A Single-Chip Signal Processor in Silicon Photonics Technology

Hong Deng

Supervisors: Prof. Wim Bogaerts, Prof. Gunther Roelkens

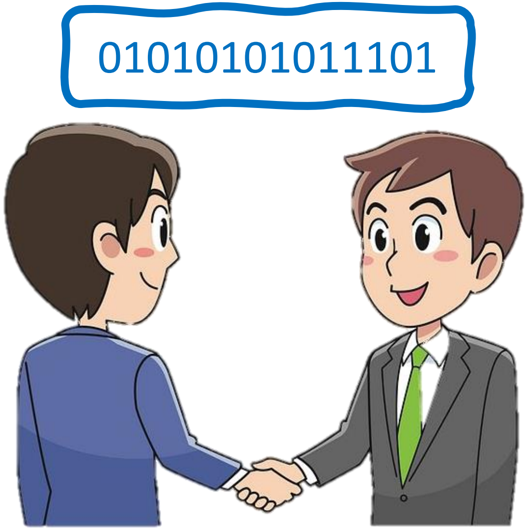
GHENT UNIVERSITY

imec
embracing a better life

Communication

Hello 你好 hallo こんにちわ
ciao 안녕하세요 Olá
Здравейте blah-blah-blah

COMMUNICATION: IN TROUBLE



Communication Failed   But why?

Communication System :

Shannon Limit:

$$C = B\log_2(1+\frac{S}{N})$$

Channel capacity

Bandwidth (frequency)

Received Signal Power

Channel Noise Power

01010101011101

Cannot handle the information:
B is not enough

Signal is too weak:
S is too Low

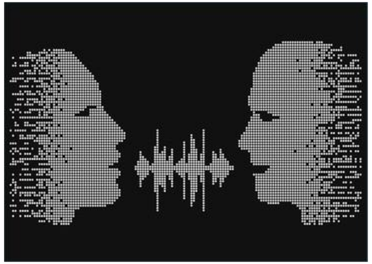
Noise is too loud:
N is too high

GHENT UNIVERSITY imec

Communication System: Larger Capability

$$C = B\log_2(1+\frac{S}{N})$$ → Larger B, Higher S, Lower N

Wireless



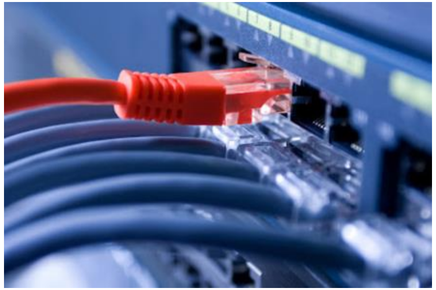
Radio Frequency Network

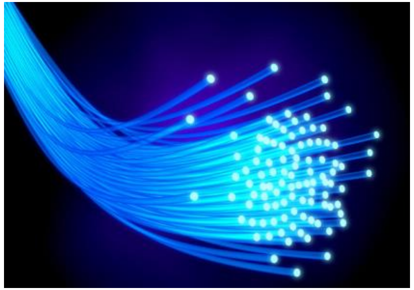
Baseband

Broadband

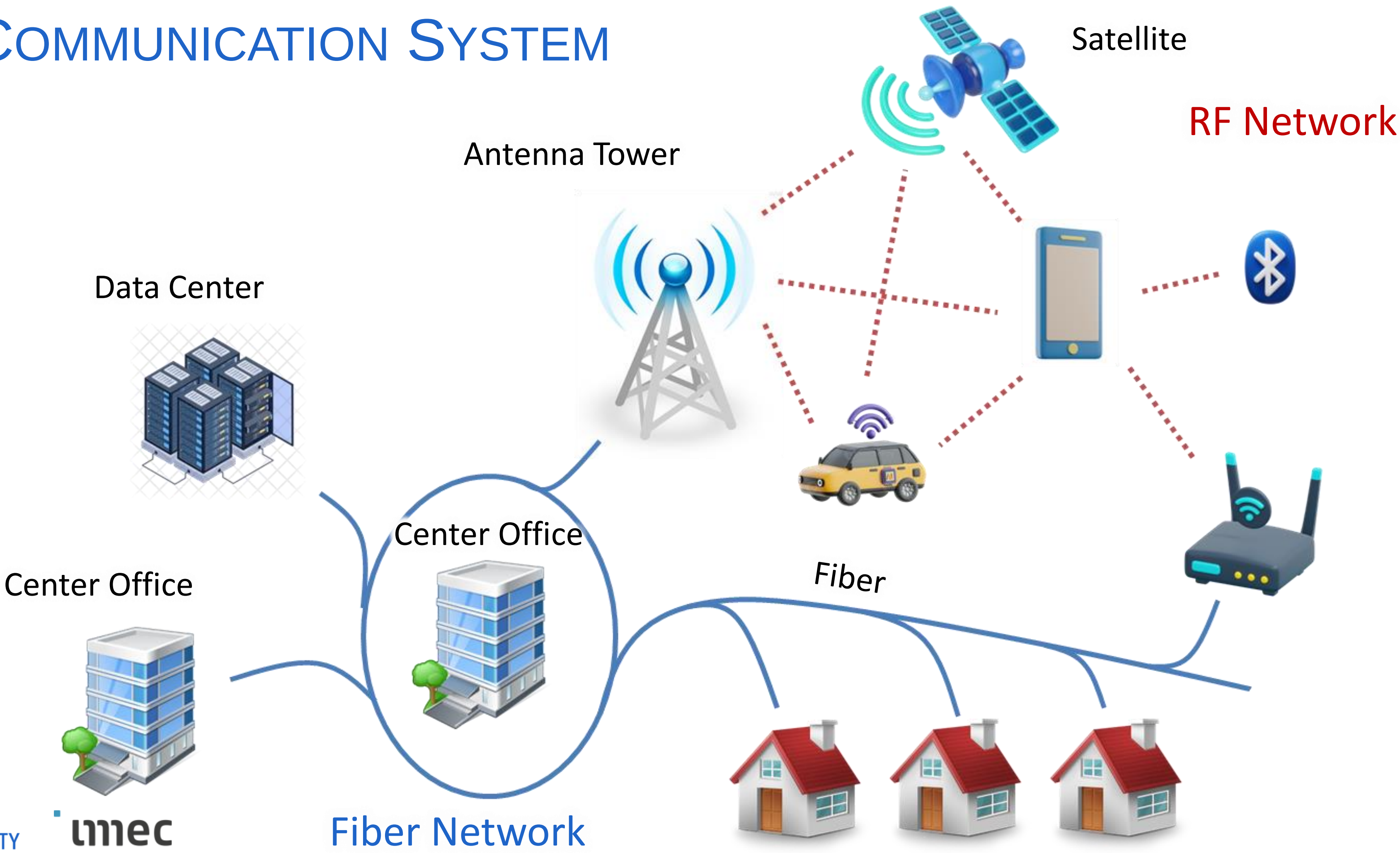
Optical Fiber Network

Wired





Communication System



Communication System:

Now, we have communication systems with large capacity

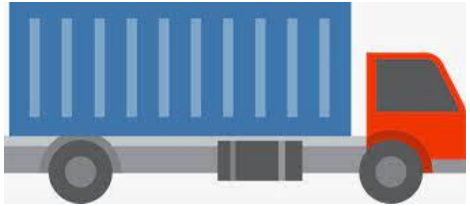
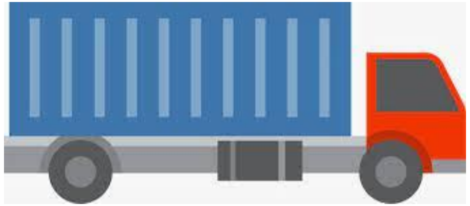
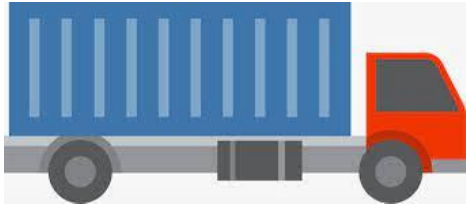
However, maybe the channel capacity
is too large for a single user

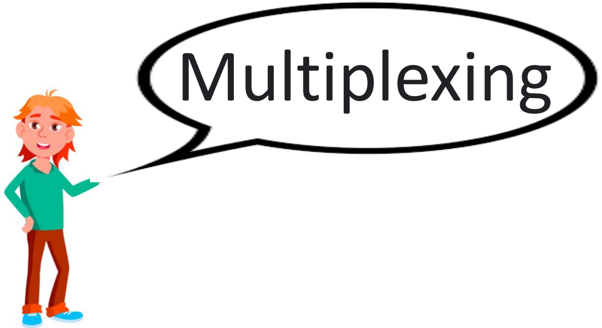
Communication System: Multiplexing

Thus, we can combine multiple users' data

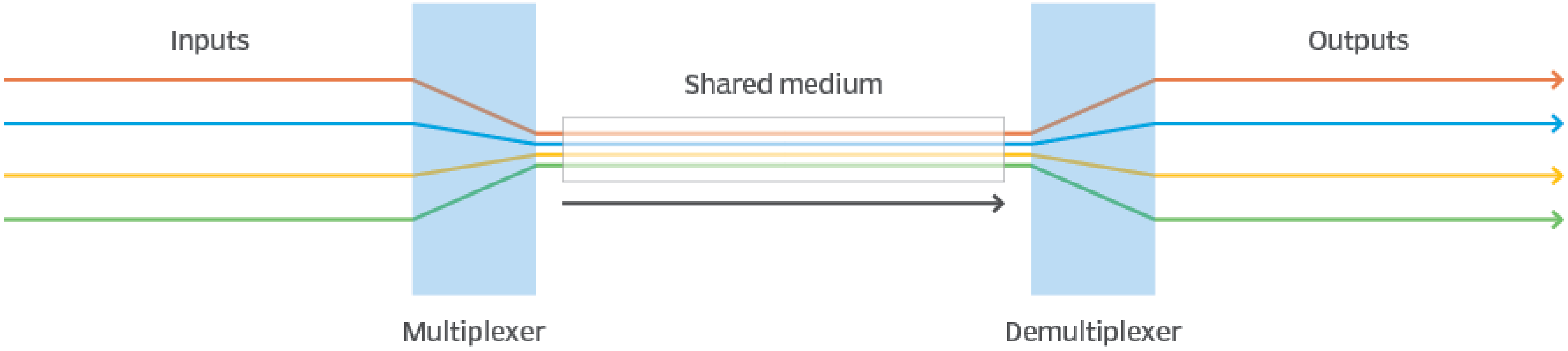




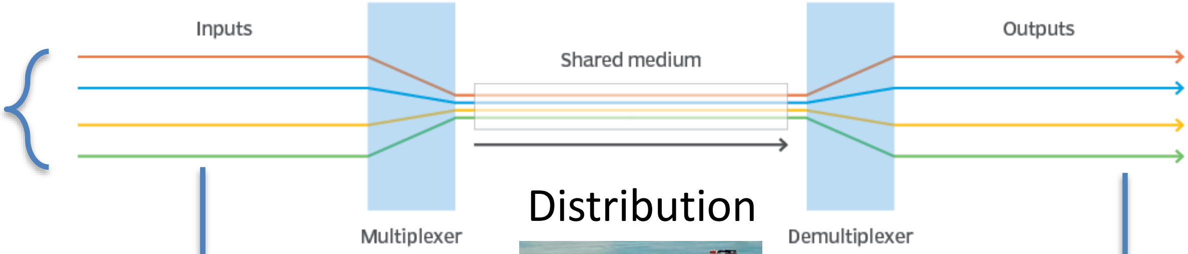







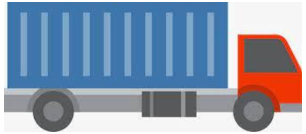
Communication System: Multiplexing



Communication System:



Different carriers



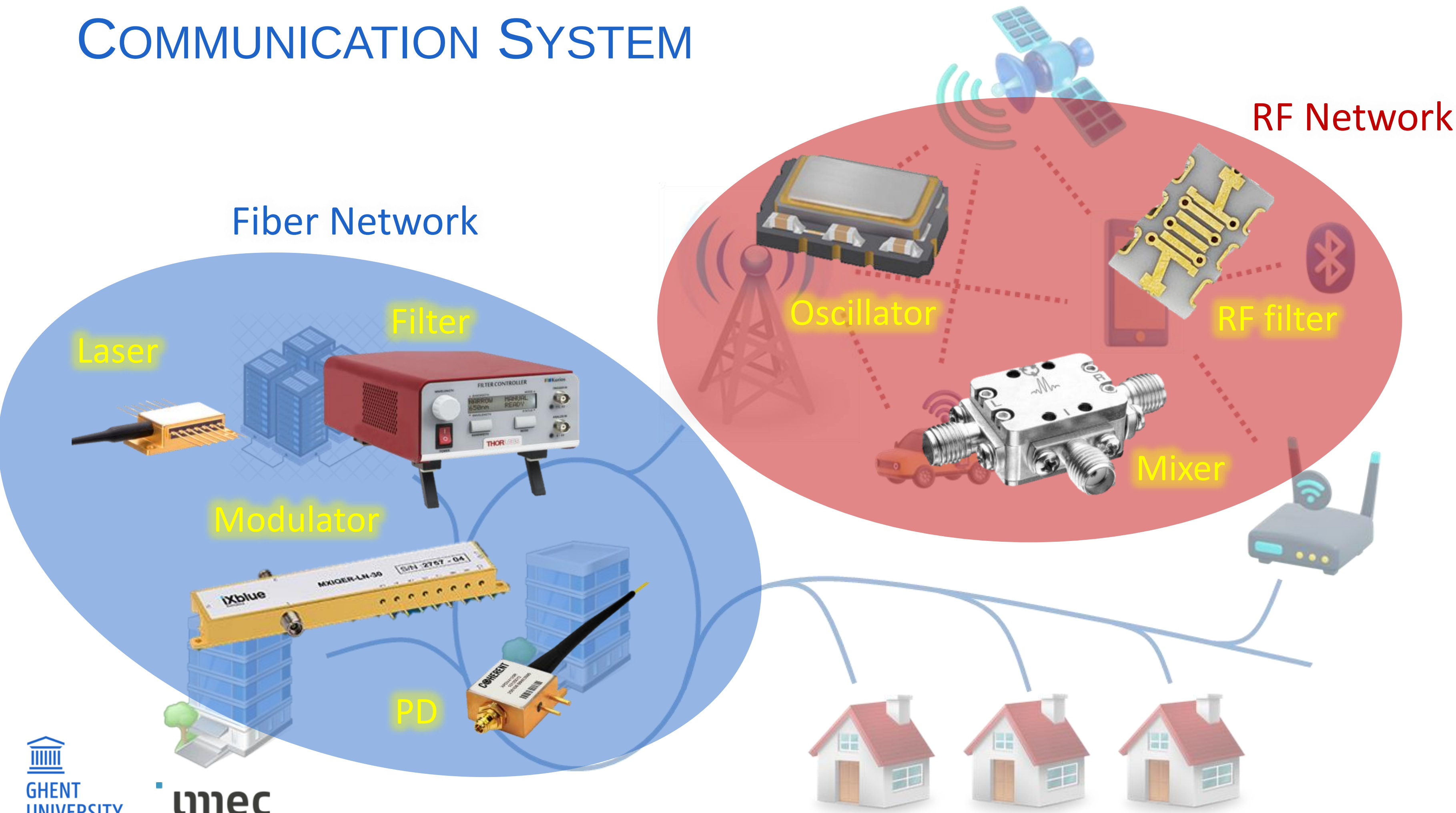
Signal loading

Distribution

Signal combiner filter

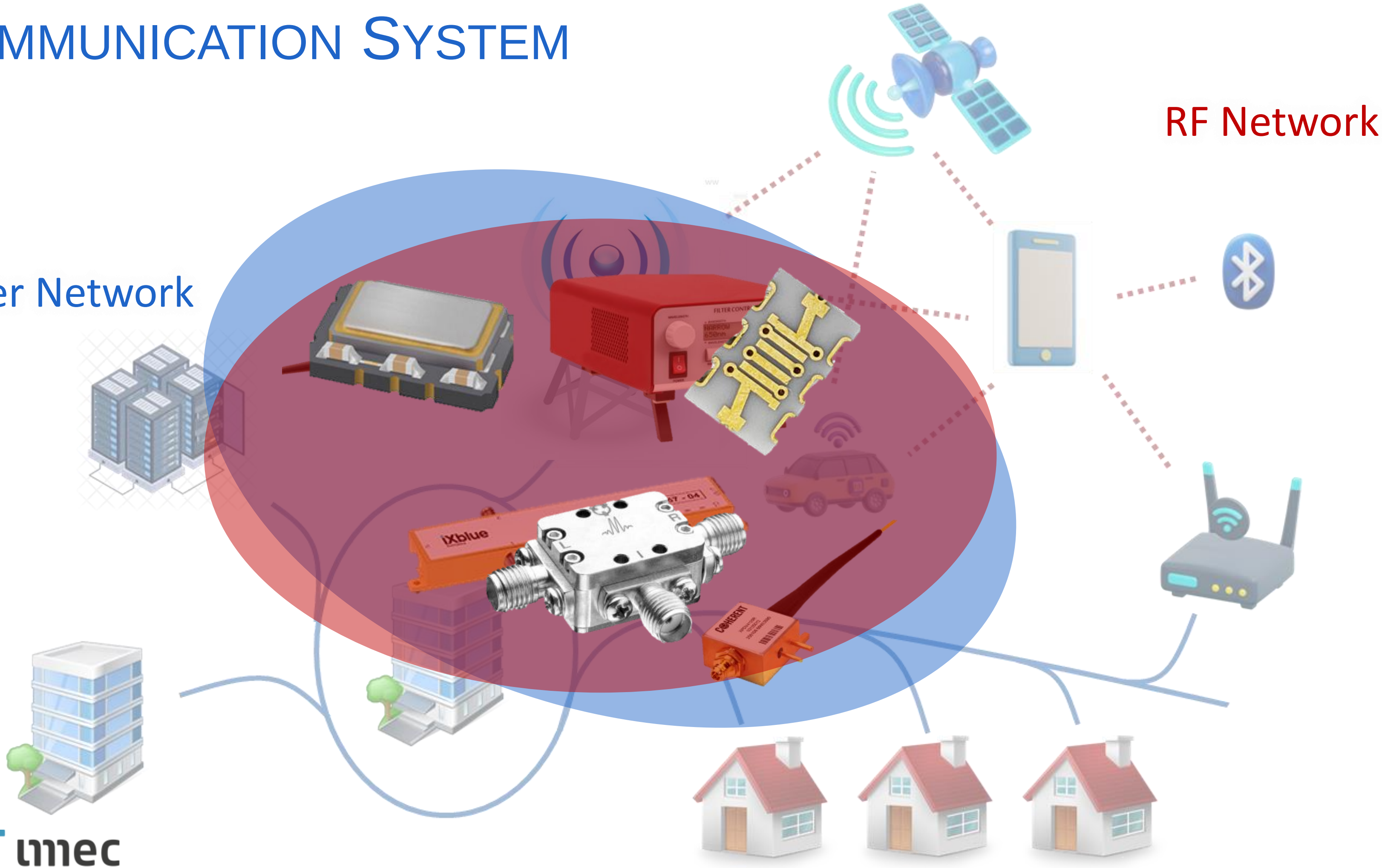
Signal detection

Communication System

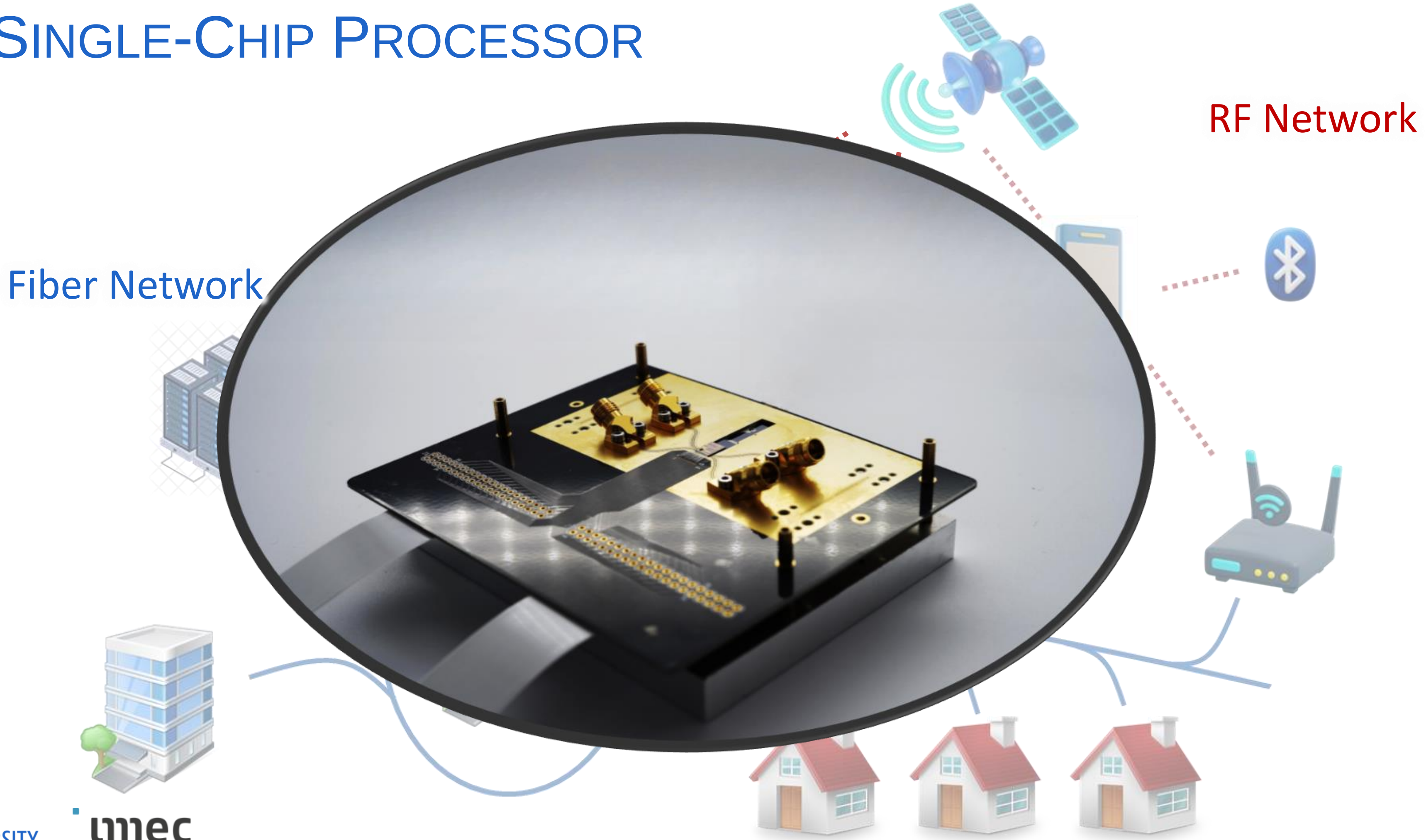


GHENT UNIVERSITY imec

Communication System

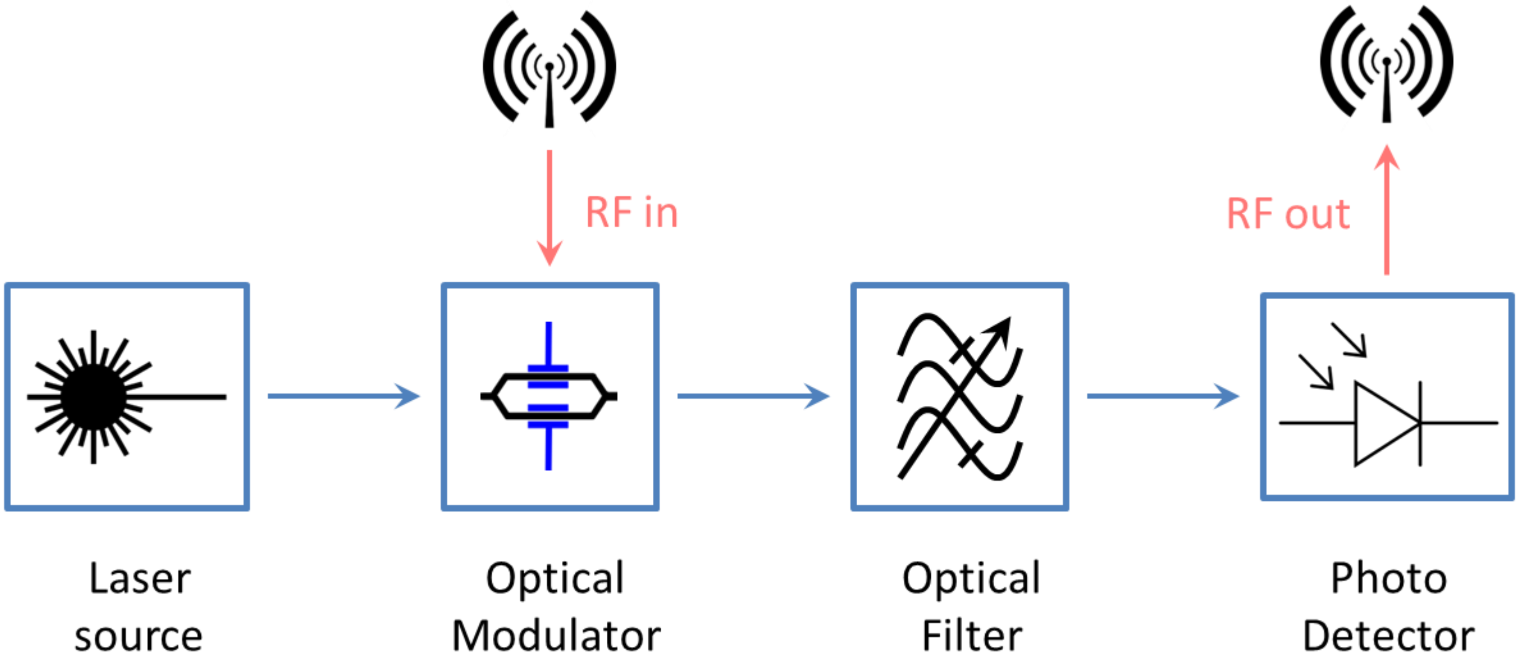


Single-Chip Processor

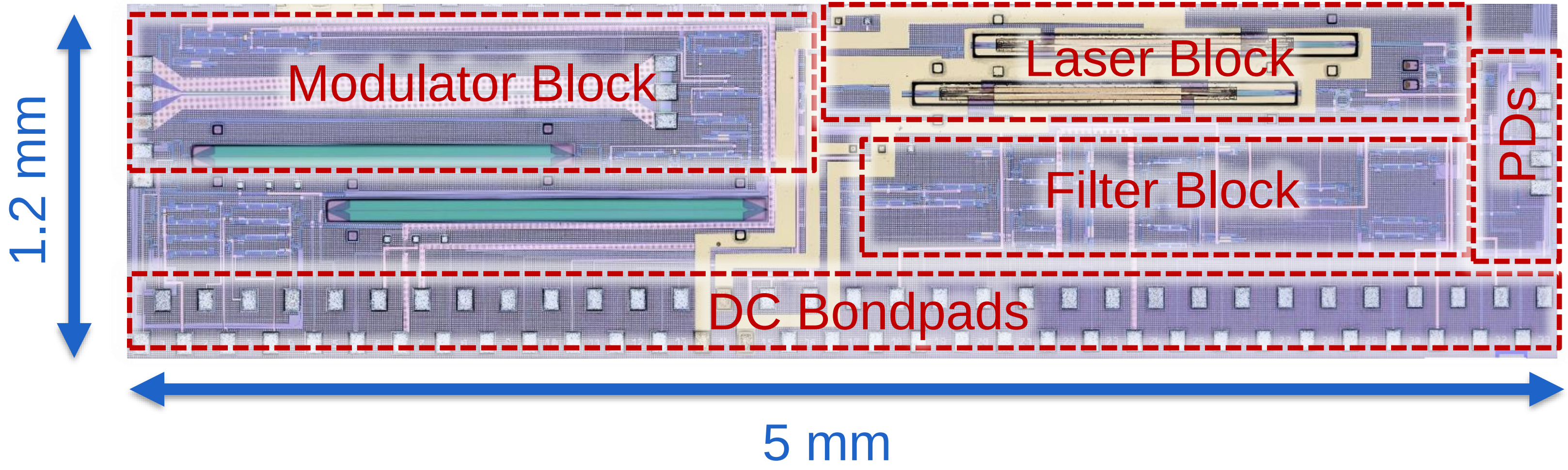


How to manipulate RF signal in Optical domain

Microwave Photonics



Single-Chip Processor

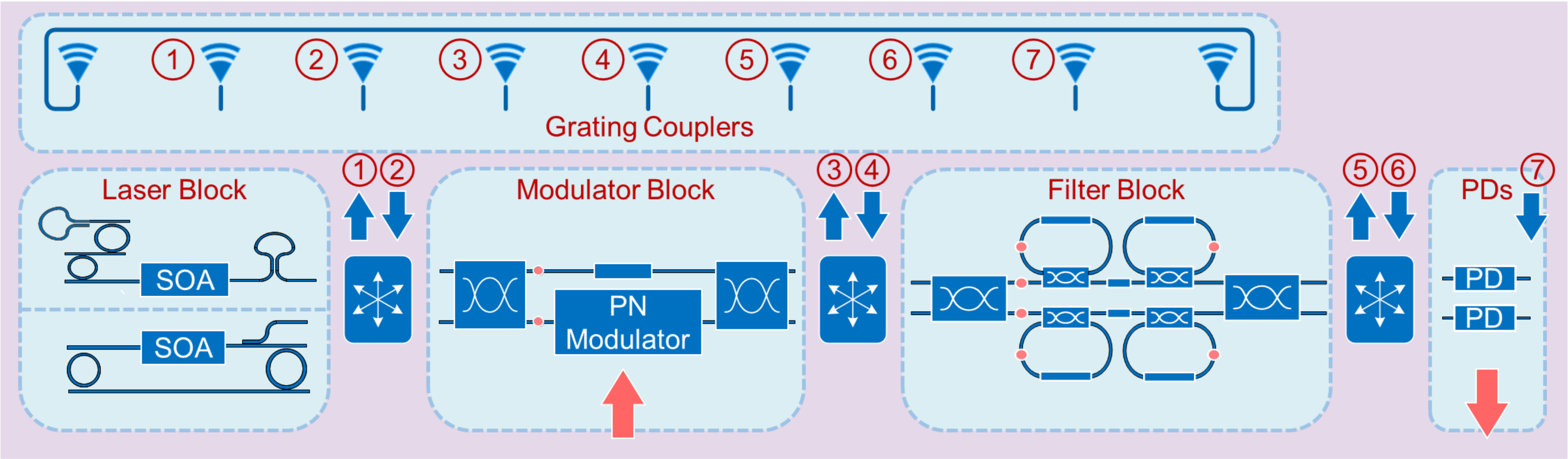


Contains:
2 transfer printed tunable lasers, 15 optical in/outs, 3 RF in/outs, 52 thermal tuners, 8 PD monitors

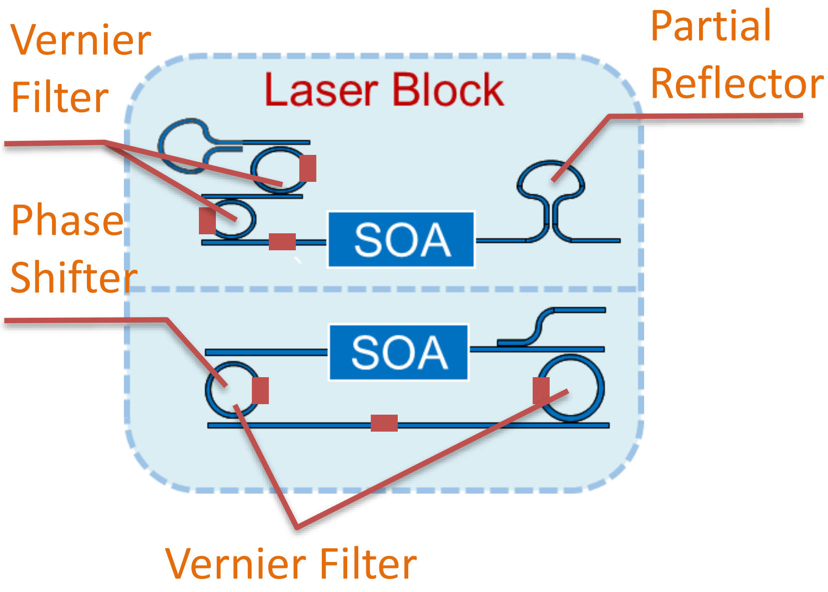
GHENT UNIVERSITY imec

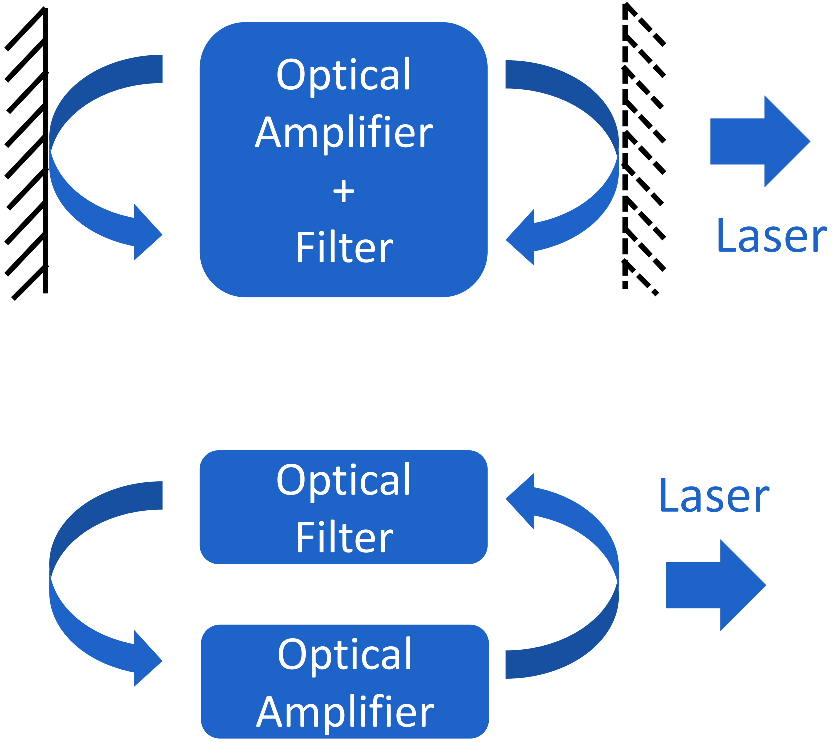
H. Deng, J. Zhang, E. Soltanian, X. Chen, C. Pang, N. Vaissiere, D. Neel, J. Ramirez, J. Decobert, N. Singh, G. Torfs, G. Roelkens, W. Bogaerts, Single-Chip Silicon Photonic Processor for Analog Optical and Microwave Signals, Nature, under review.

Single-Chip Processor



Single-Chip Processor: On-Chip Laser





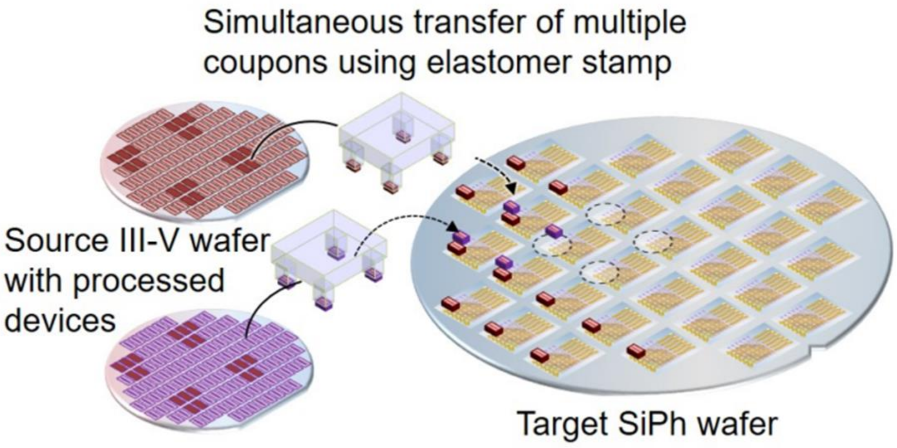
Designs provided by Dr. Jing Zhang

Single-Chip Processor: On-Chip Laser

Optical Amplifier

Silicon → cannot provide optical gain

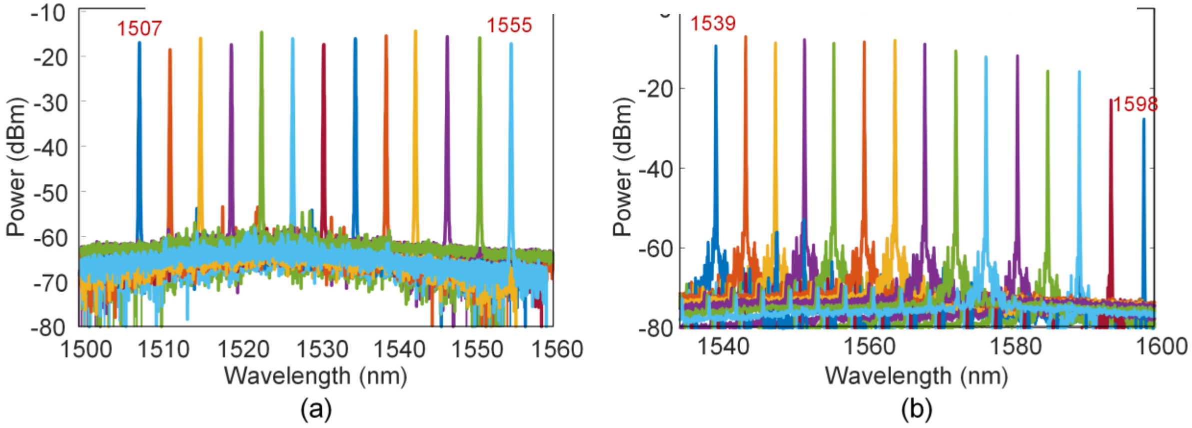
→ Micro-Transfer-Printed SOA



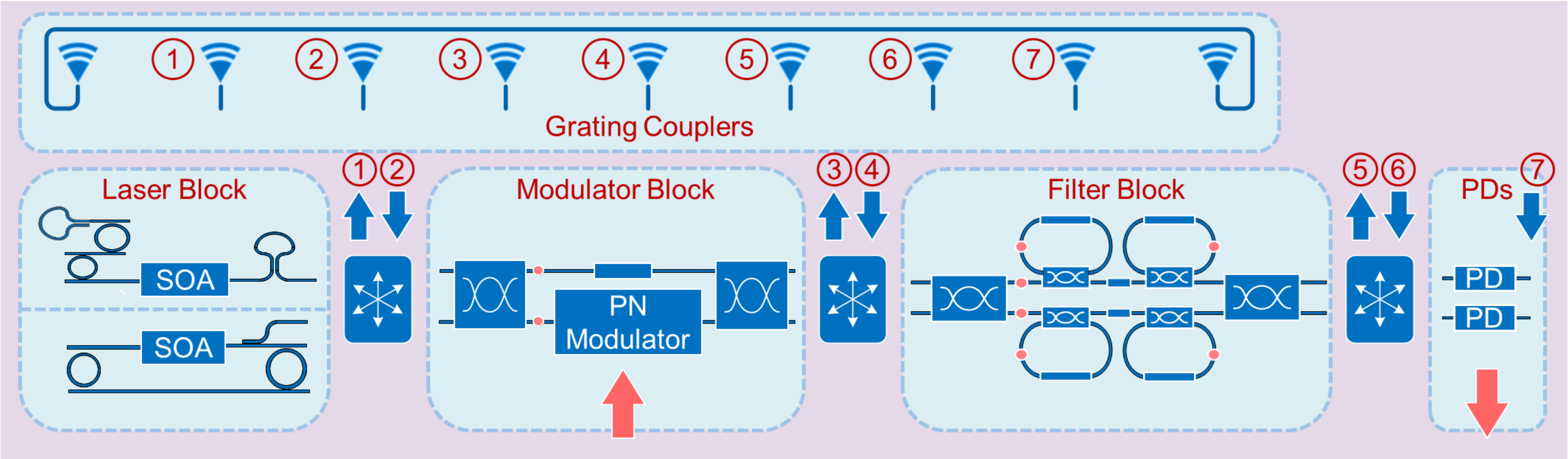
Optical Filter

Two Ring filters

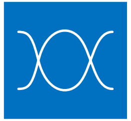
→ Mode selecting

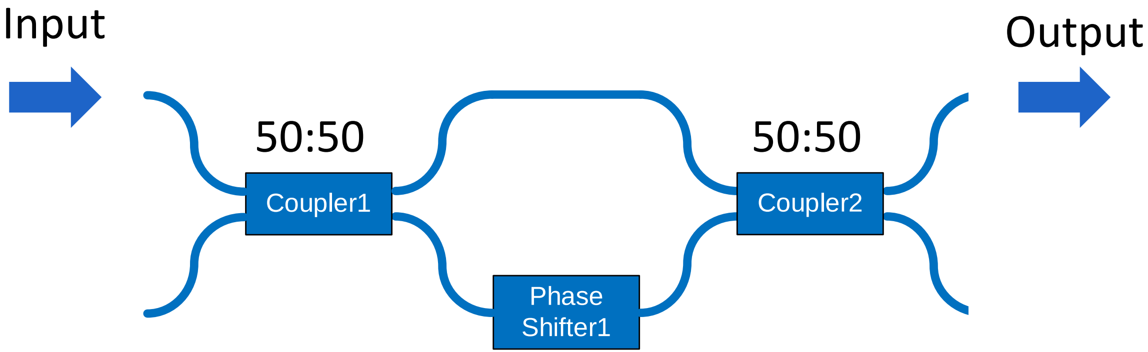


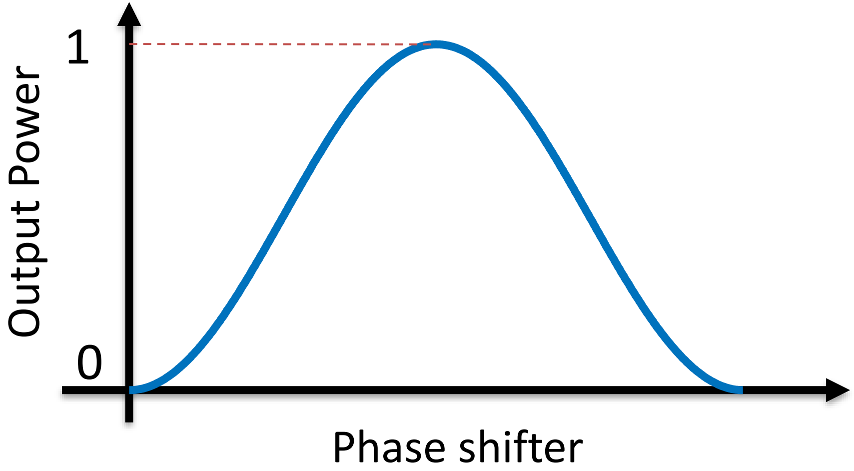
Single-Chip Processor



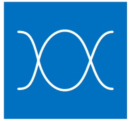
SINGLE-CHIP PROCESSOR: TUNABLE COUPLER

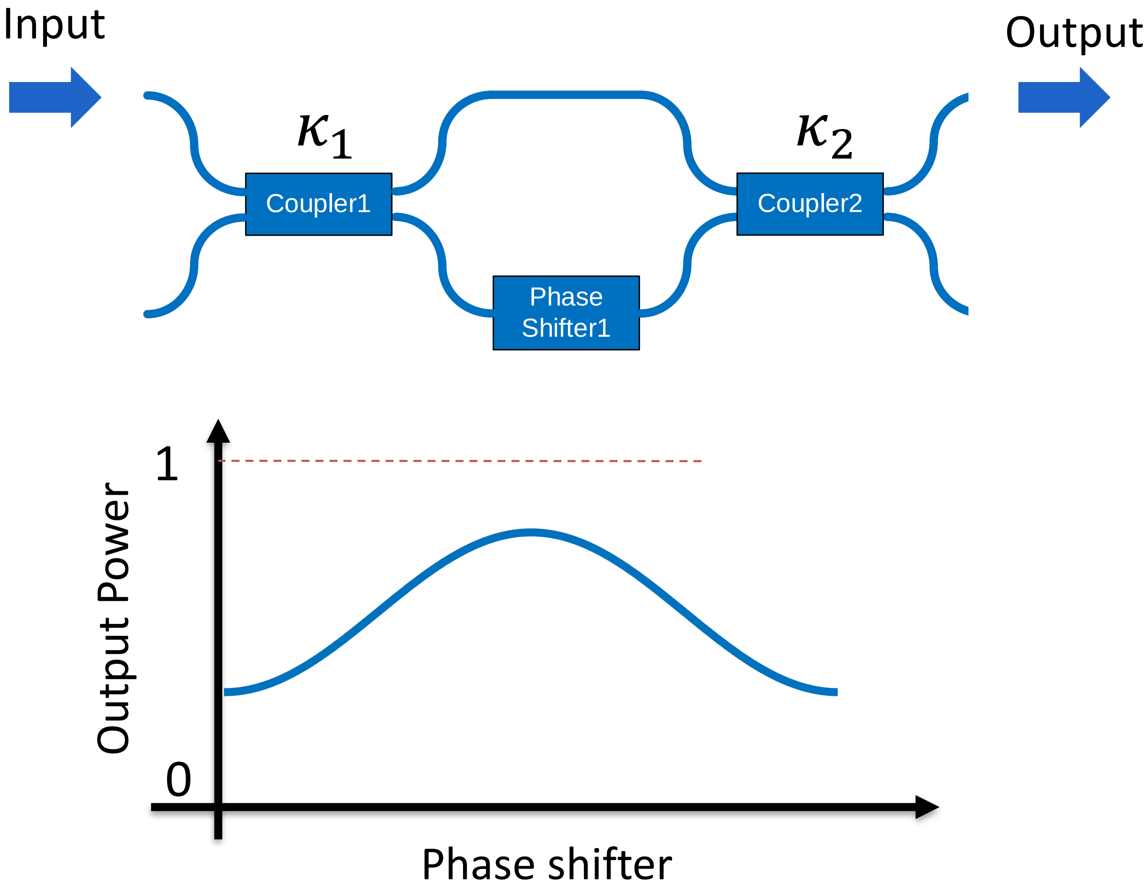




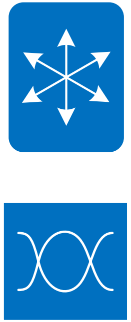


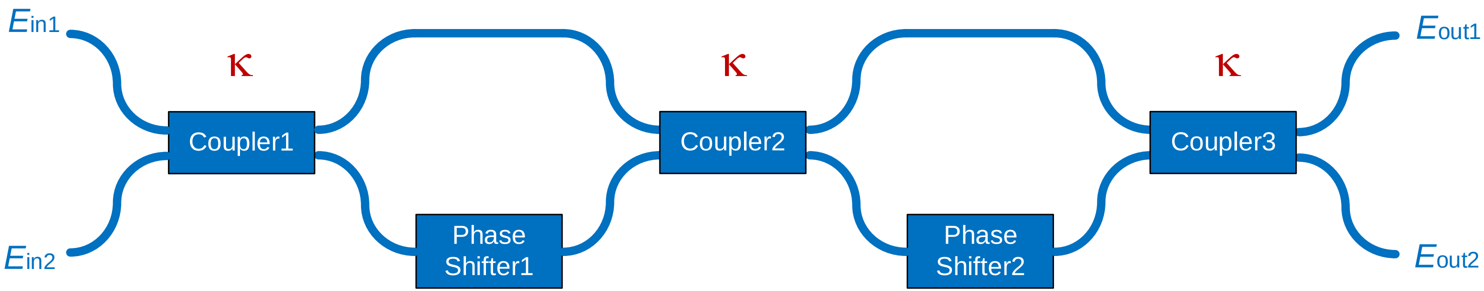
SINGLE-CHIP PROCESSOR: TUNABLE COUPLER

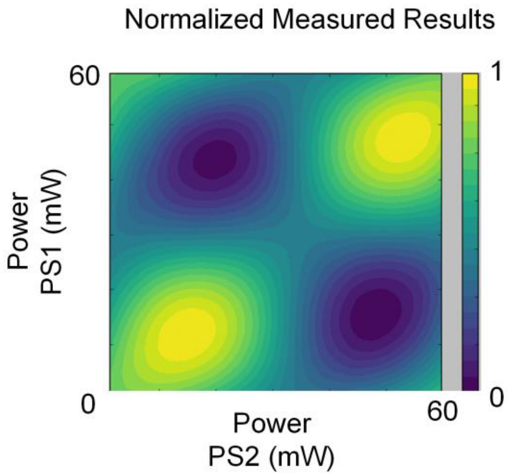




SINGLE-CHIP PROCESSOR: TUNABLE COUPLER







Can be tunned from 0 to 1

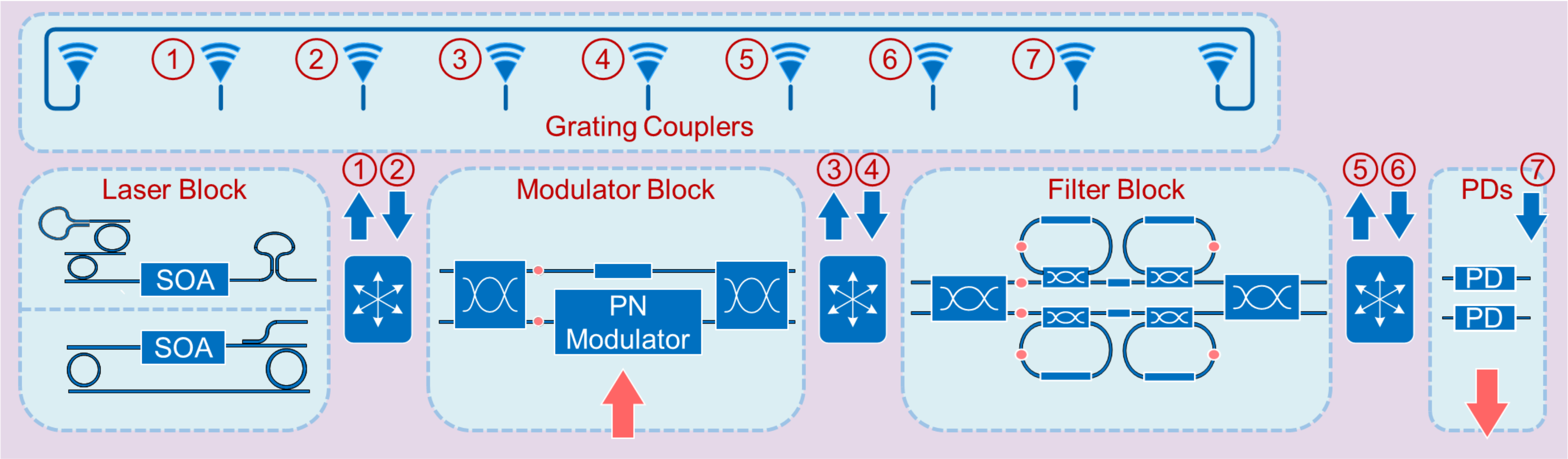
(Extinction ~ 60dB)

when κ is within (0.25, 0.75)

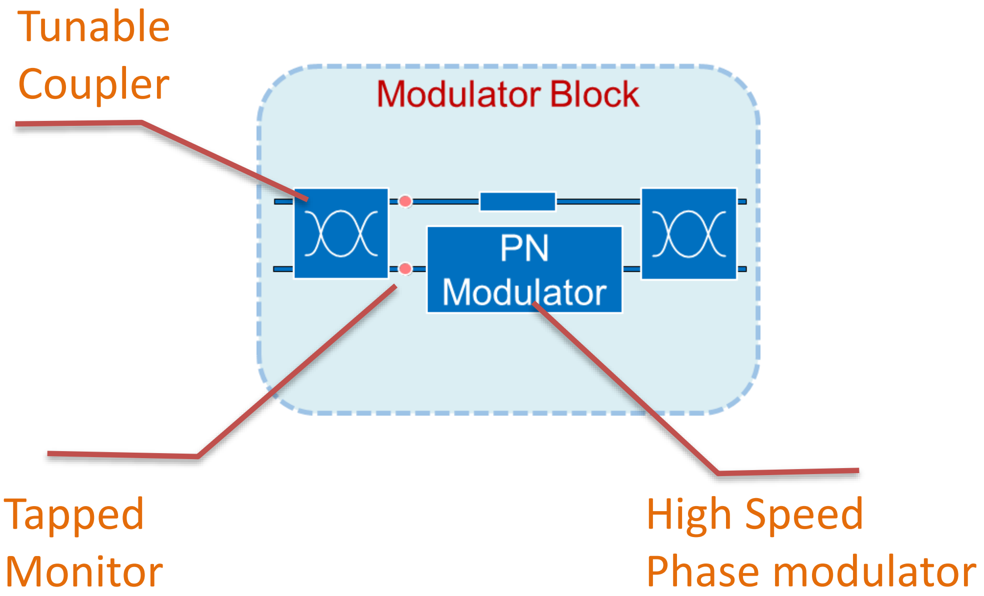
GHENT UNIVERSITY imec

M. Wang, A. Ribeiro, Y. Xing, W. Bogaerts, Tolerant, Broadband Tunable 2x2 Coupler Circuit, Optics Express, 28(4), p.5555-5566 doi:10.1364/OE.384018 (2020)

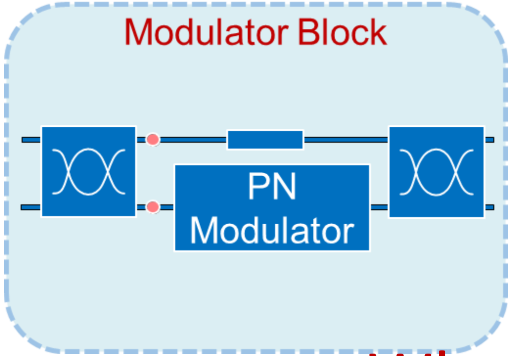
Single-Chip Processor

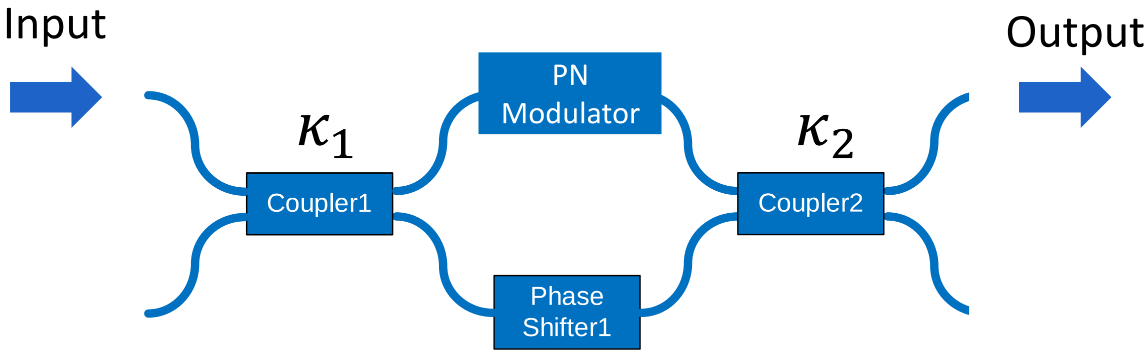


SINGLE-CHIP PROCESSOR: RECONFIGURABLE MODULATOR

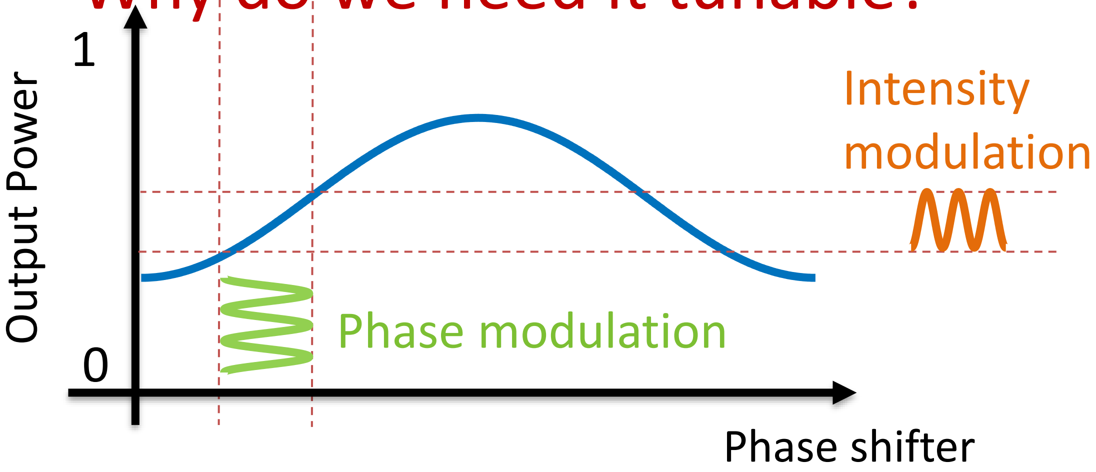


Single-Chip Processor: Reconfigurable Modulator

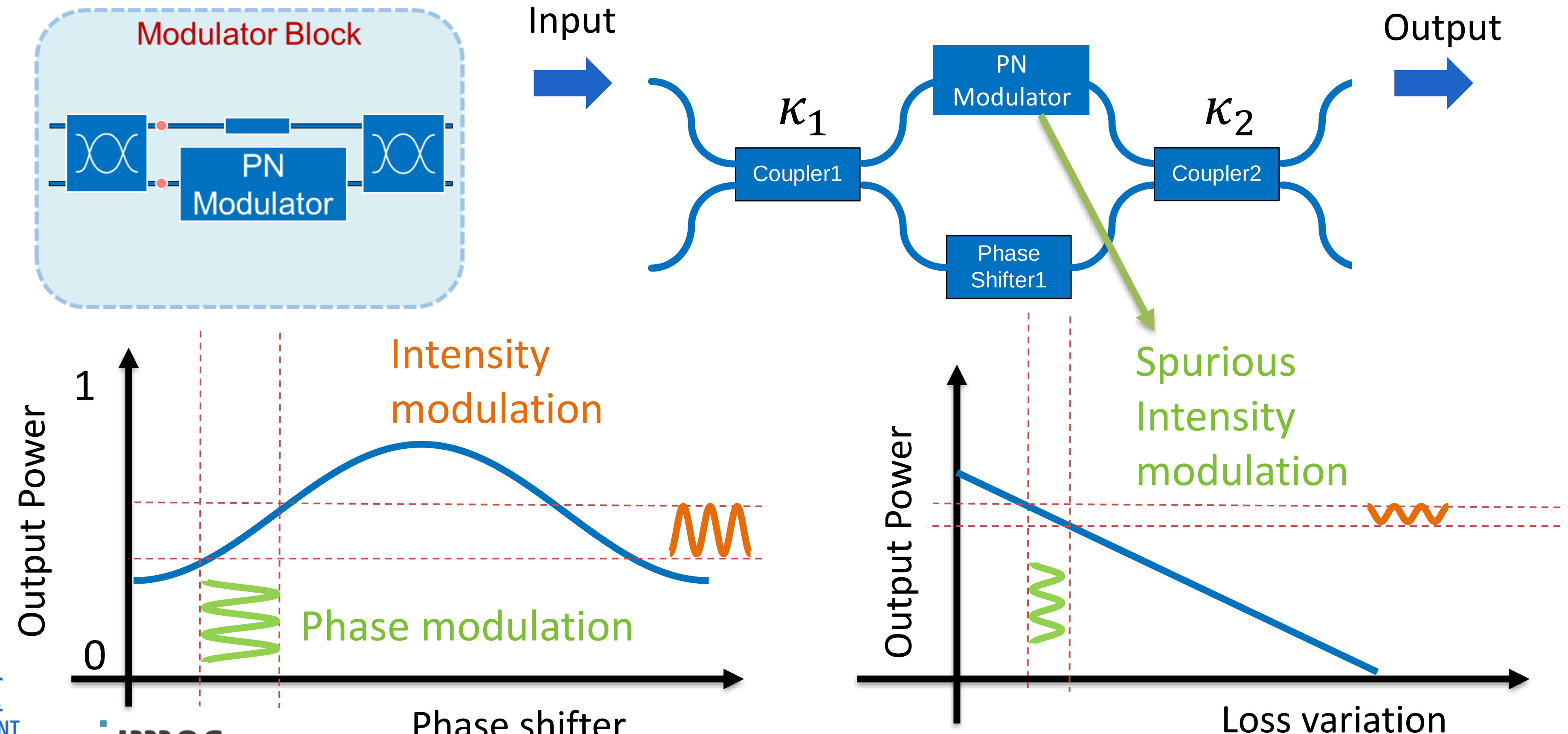




Why do we need it tunable?



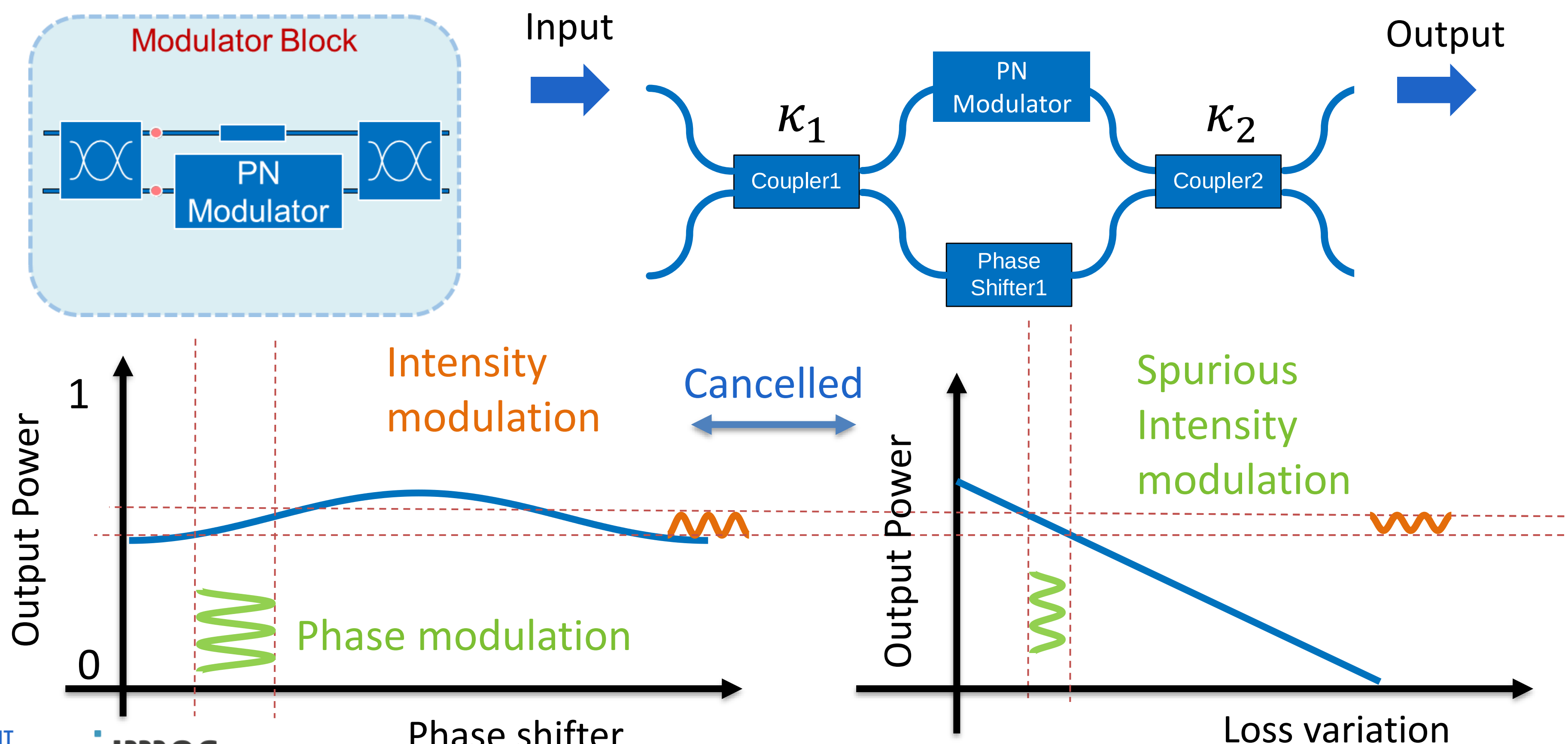
Reconfigurable Modulator: Pure Phase Modulation



GHENT UNIVERSITY

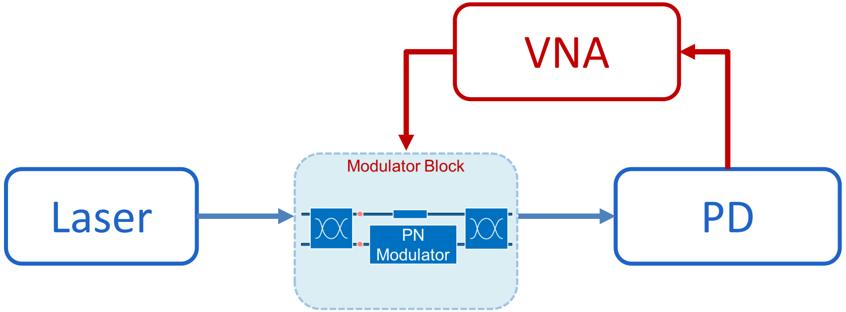
imec

Reconfigurable Modulator: Pure Phase Modulation

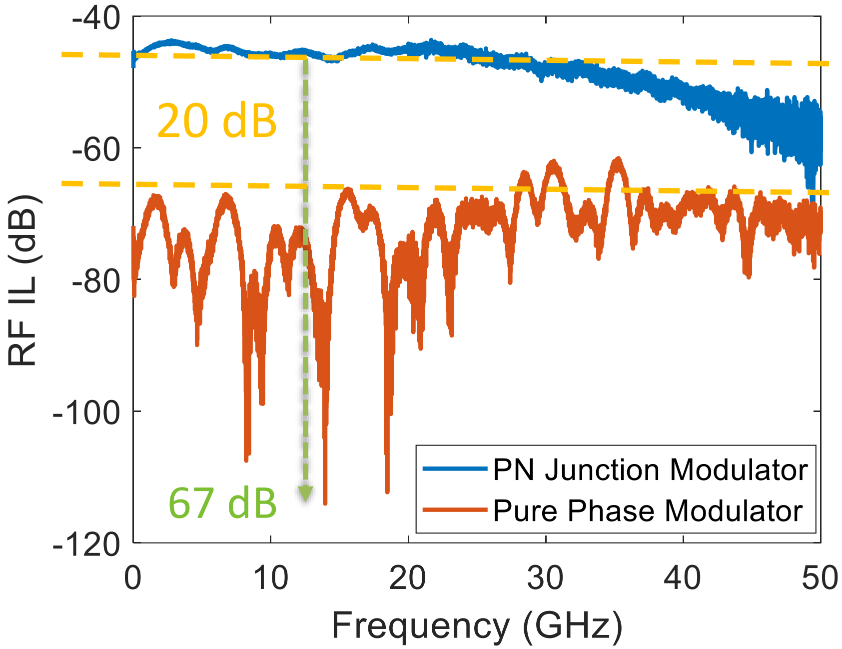


GHENT UNIVERSITY imec

Reconfigurable Modulator: Pure Phase Modulation



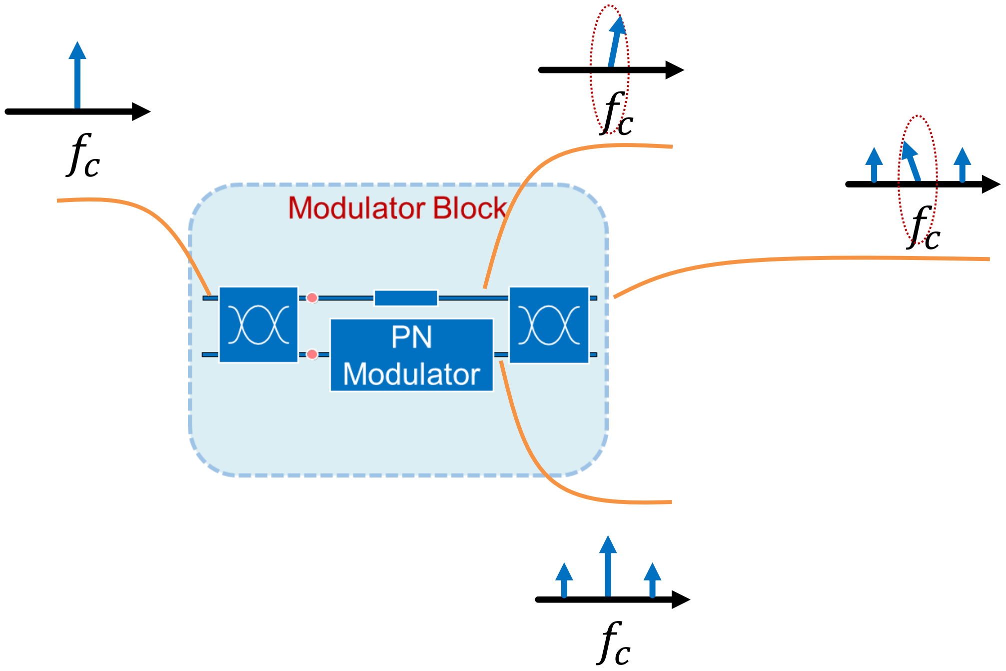
Ideal Pure Phase modulator
→ PD no signal out



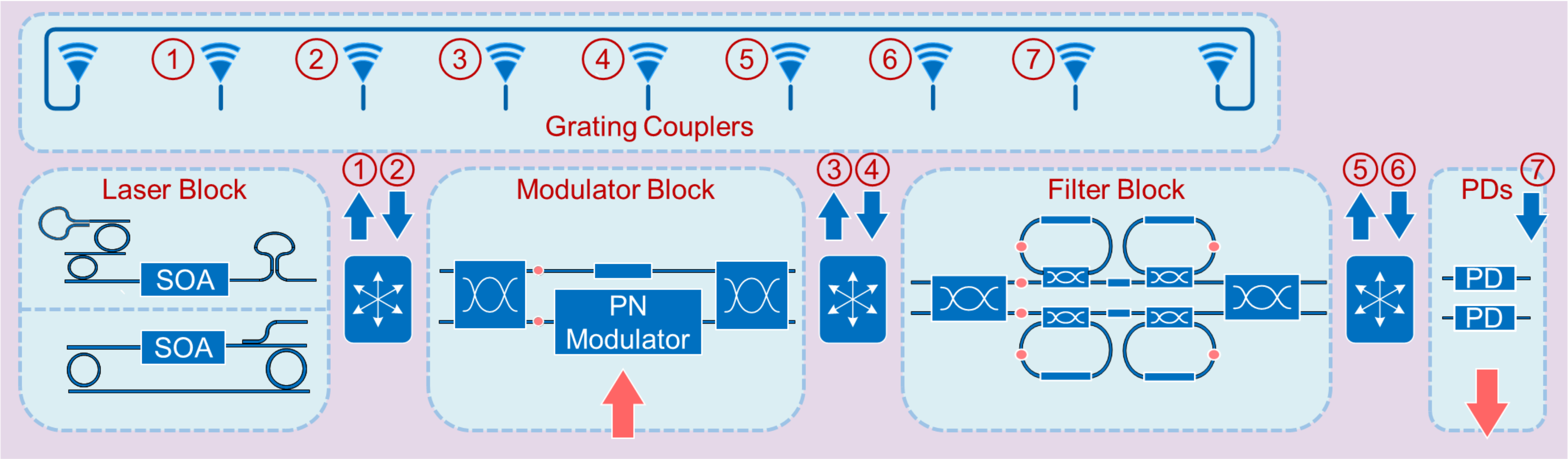
GHENT UNIVERSITY
imec

Reconfigurable Modulator: Signal Processing

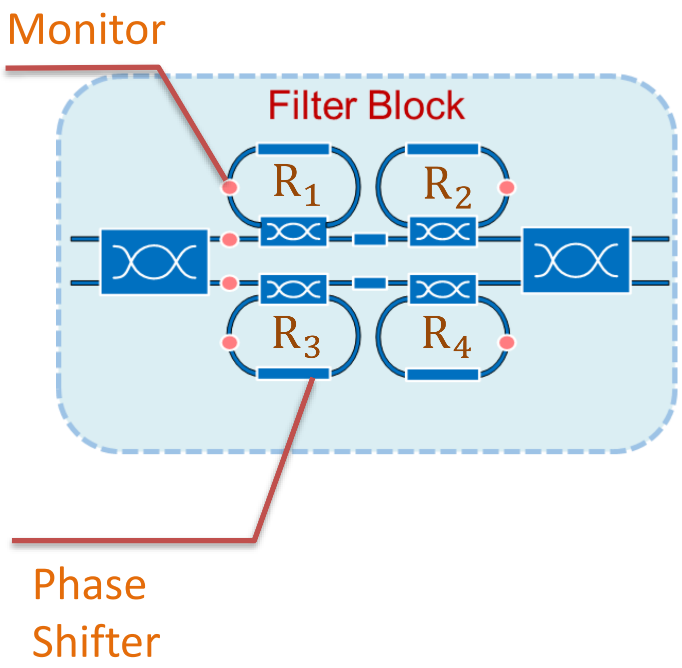
For signal processing, this modulator design offers a (phase and intensity) tunable carrier.

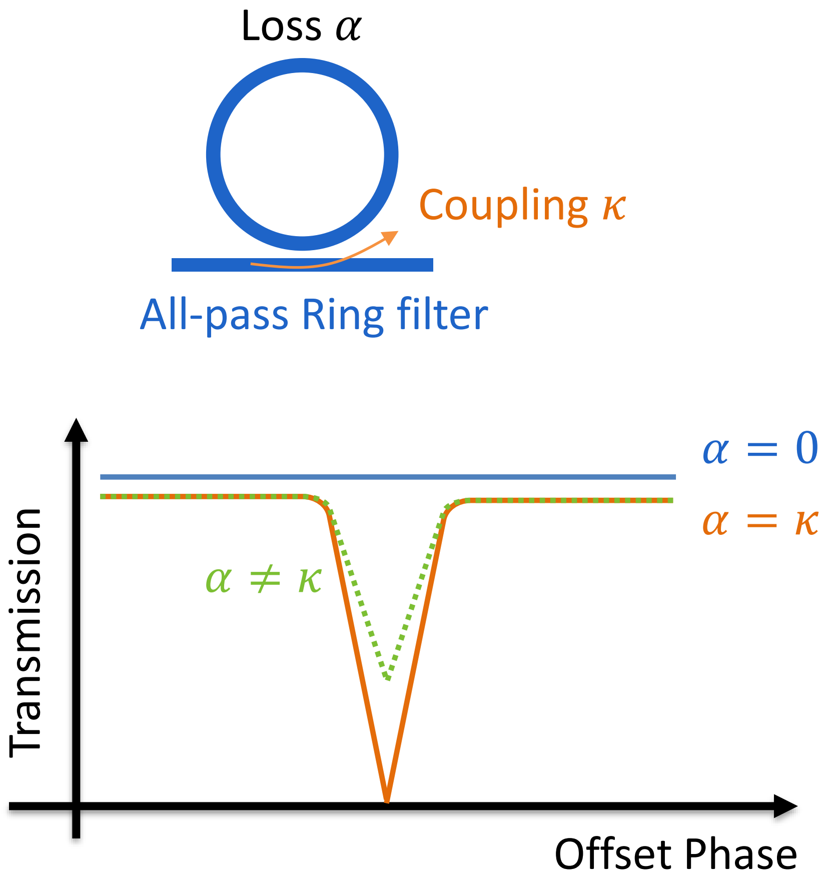


Single-Chip Processor



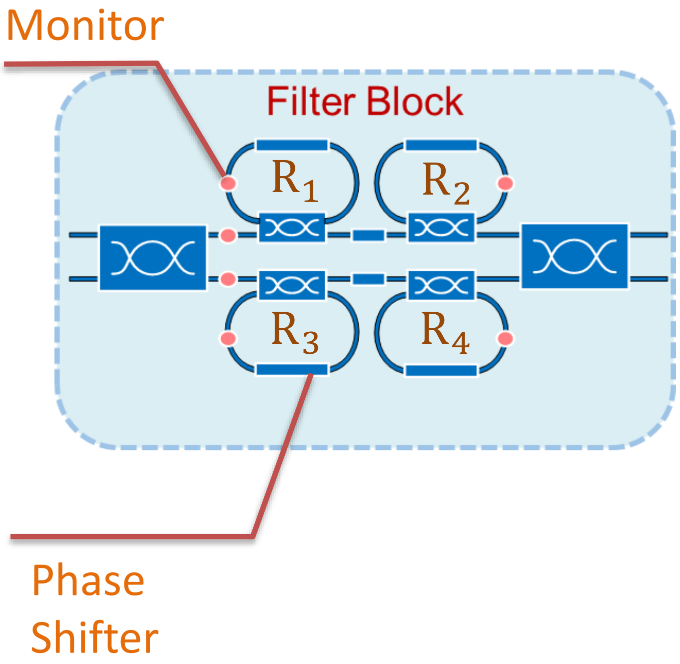
Single-Chip Processor: Tunable RLMZI

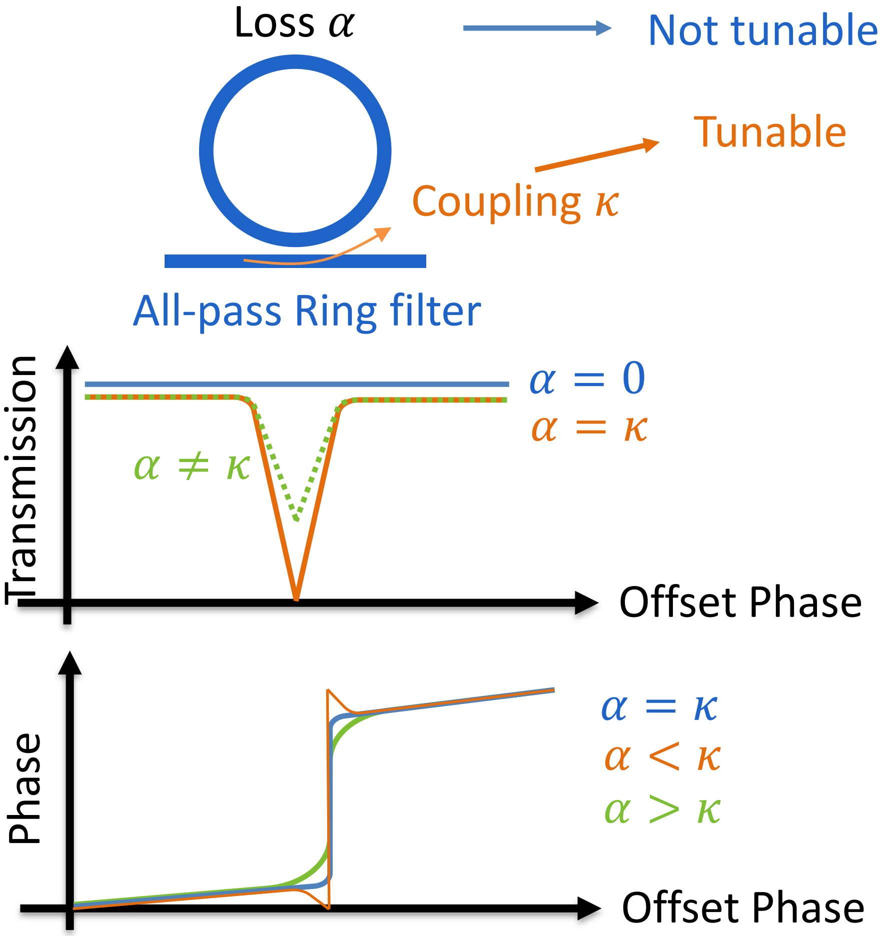




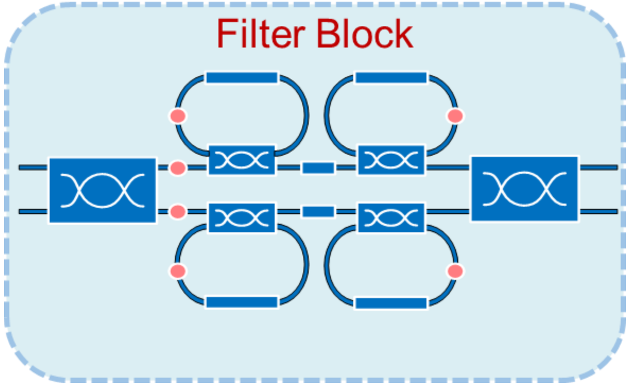
GHENT UNIVERSITY imec

SINGLE-CHIP PROCESSOR: TUNABLE RLMZI





Single-Chip Processor: Tunable RLMZI



"Optimum bandpass filters can be realized as the sum or difference of two all-pass functions"

Optical Filter Design and Analysis: A Signal Processing Approach

around the center of the polynomial, i.e., the coefficient of z^k is the same as the coefficient of z^{p-k}. An example is:

$$3z^4 - z^3 + 6z^2 - z + 3.$$

Such $\hat{f}(z)$ polynomials are called mirror-image (MI) polynomials.

coefficient of z^{p-k}. An example is

$$4z^5 - 5z^4 + 14z^3 - 14z^2 + 5z - 4.$$

Such $\hat{f}(z)$ polynomials are called anti-mirror-image (AMI) polynomials. As an odd polynomial $f(s)$ must be an even

Theorem 2: The necessary and sufficient condition for a transfer function in z to be realizable as the sum (difference) of two allpass functions is that the Characteristic function associated with the transfer function be a rational function of z formed as the quotient of an AMI (MI) polynomial, by an MI (AMI) polynomial, both of the same degree.

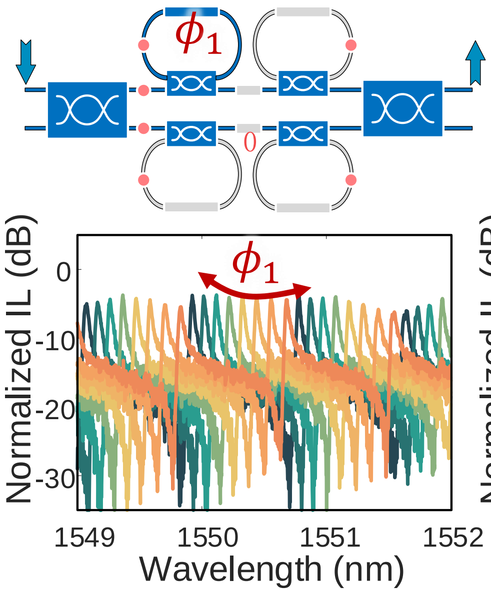
A. N. Willson and H. J. Orchard, "Insights into digital filters made as the sum of two allpass functions," in IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol. 42, no. 3, pp. 129-137, March 1995,

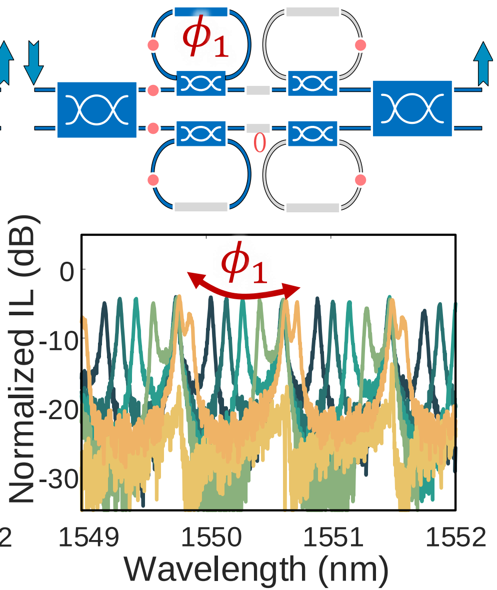
Single-Chip Processor: Tunable RLMZI

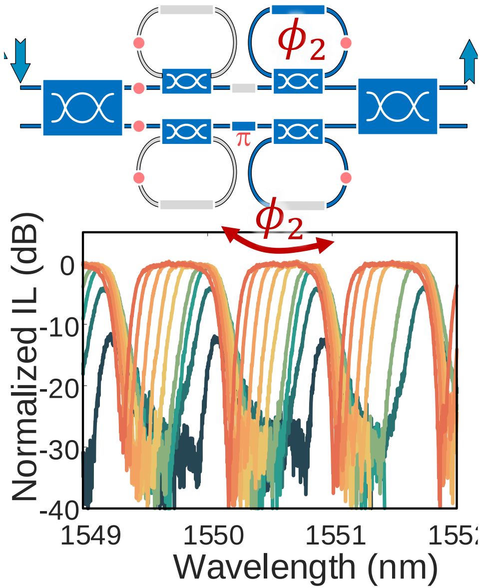
Single Pass Filter

Duo Pass Filter

Flattop bandpass Filter



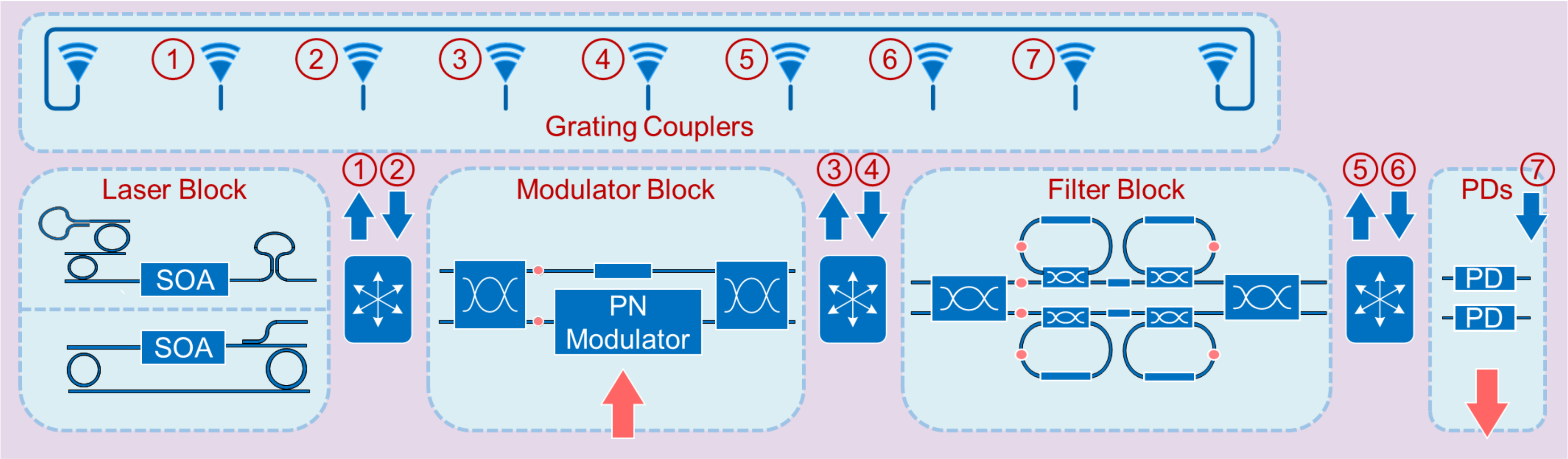




GHENT UNIVERSITY

imec

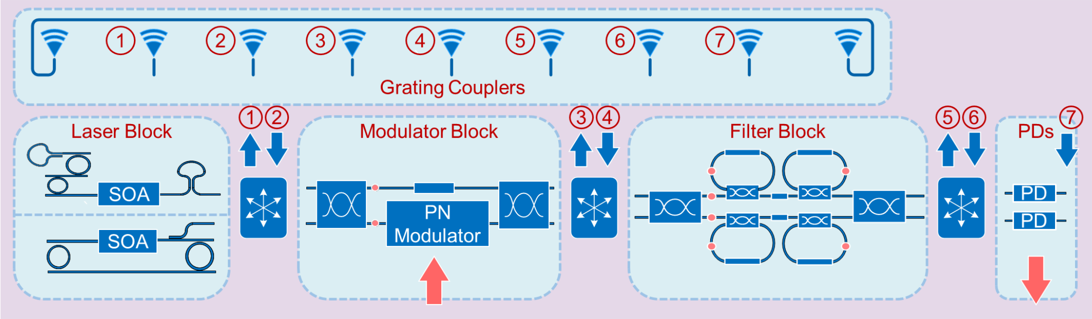
SINGLE-CHIP PROCESSOR



GHENT UNIVERSITY

imec

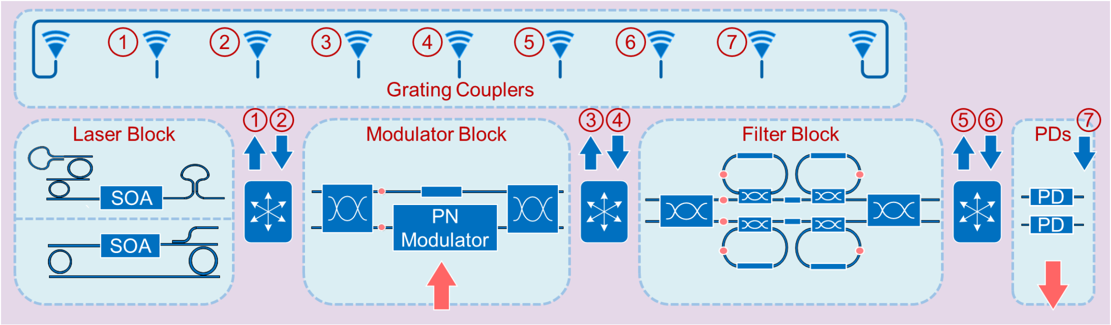
Till Now:



	Optical Functionalities	Functional block
Signal generation	Lasing on chip	Laser Block
Signal loading	Reconfigurable Modulation: Phase or Intensity	Laser Block Modulator Block
Signal filtering (Complex)	Reconfigurable Optical Filter	Filter Block
Signal Detection	High Speed photodetection	PDs

GHENT UNIVERSITY imec

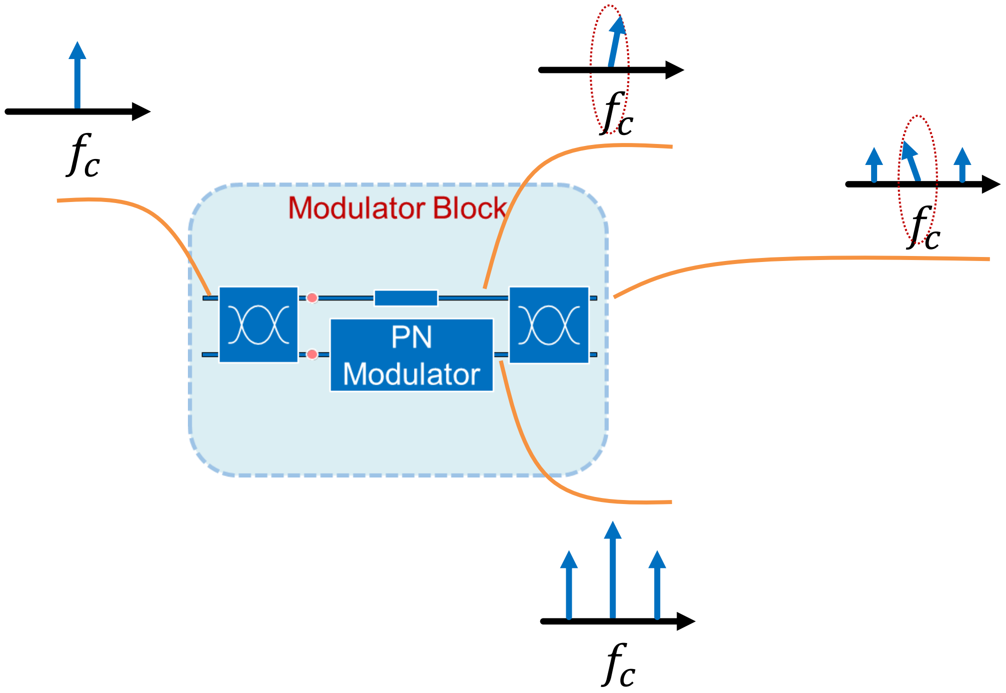
HOW TO USE



IN RF SIGNAL PROCESSING

Single-Chip Processor: Microwave photonic filter

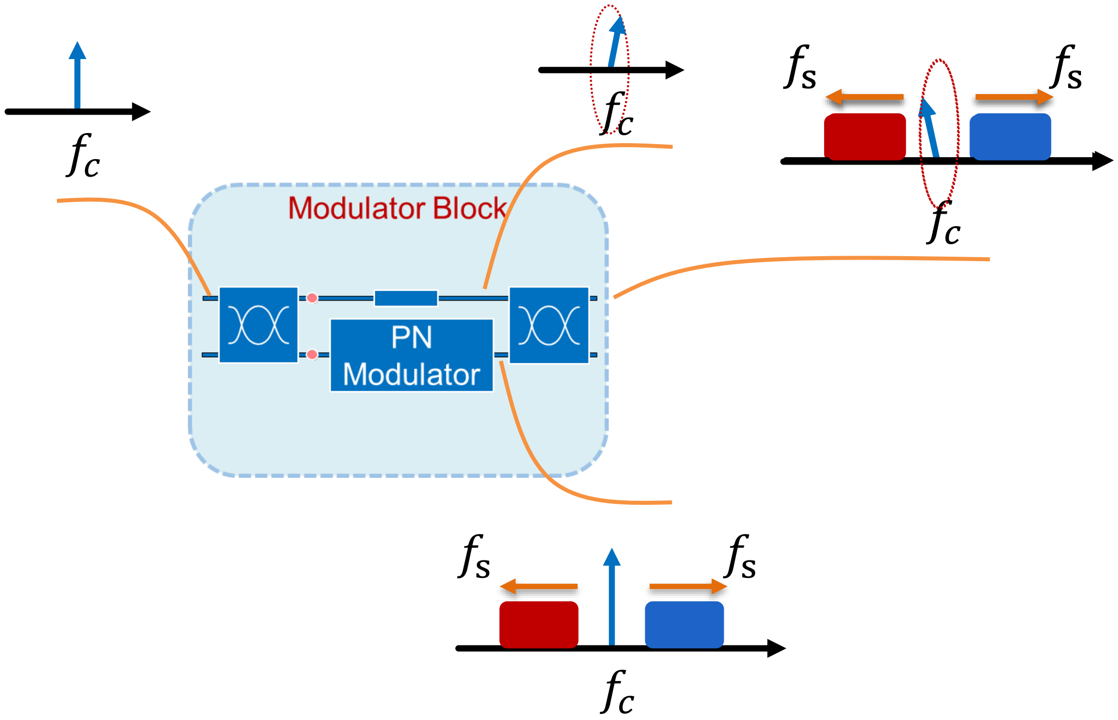
This modulator design offers a (phase and intensity) tunable carrier.



GHENT UNIVERSITY imec

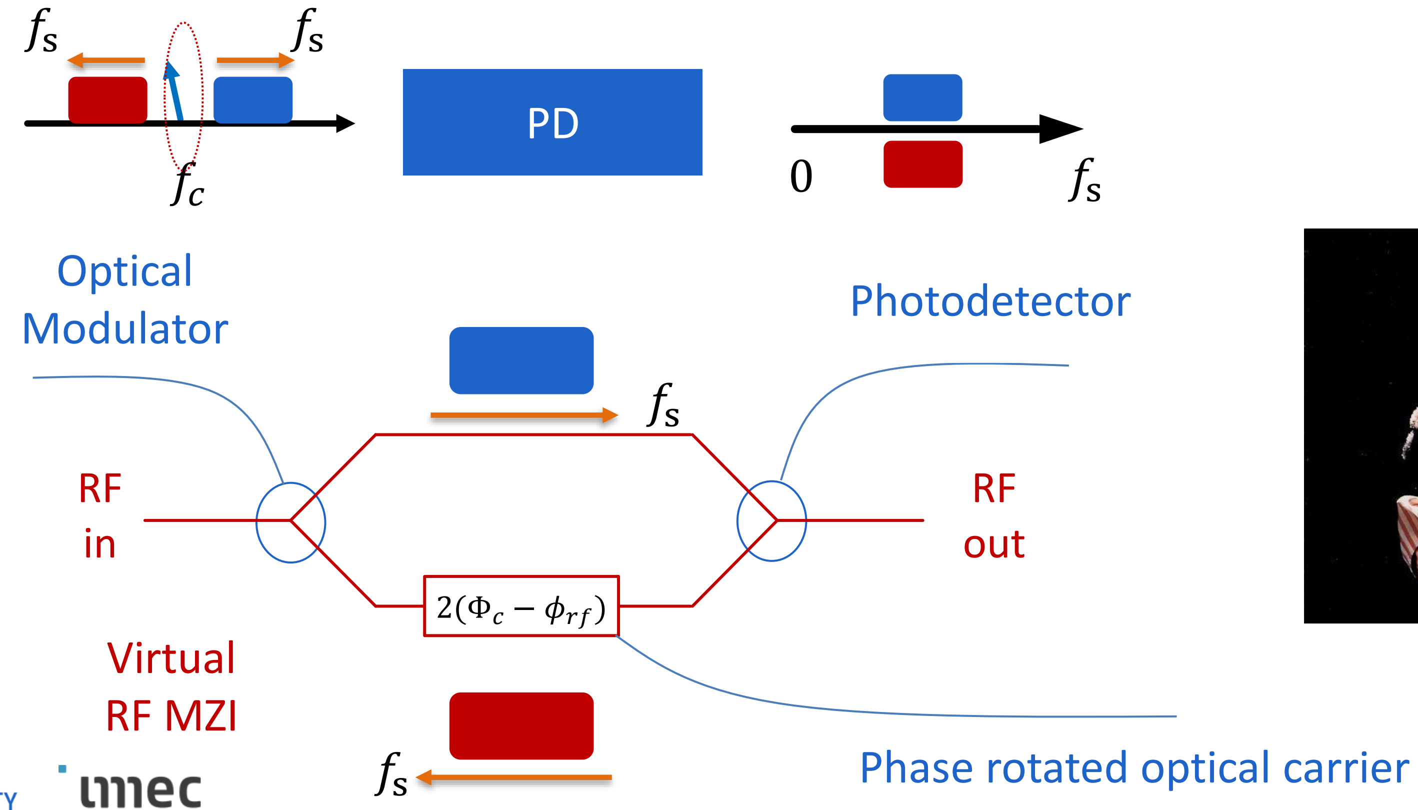
Single-Chip Processor: Microwave photonic filter

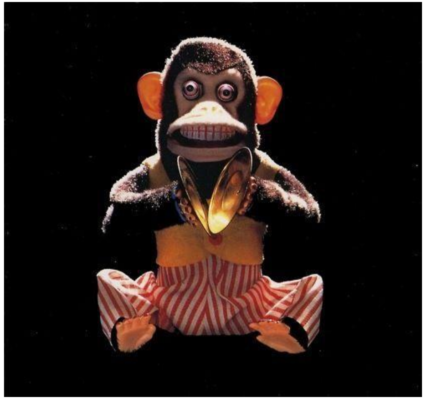
For a broadband RF signal



GHENT UNIVERSITY imec

SINGLE-CHIP PROCESSOR: MICROWAVE PHOTONIC FILTER

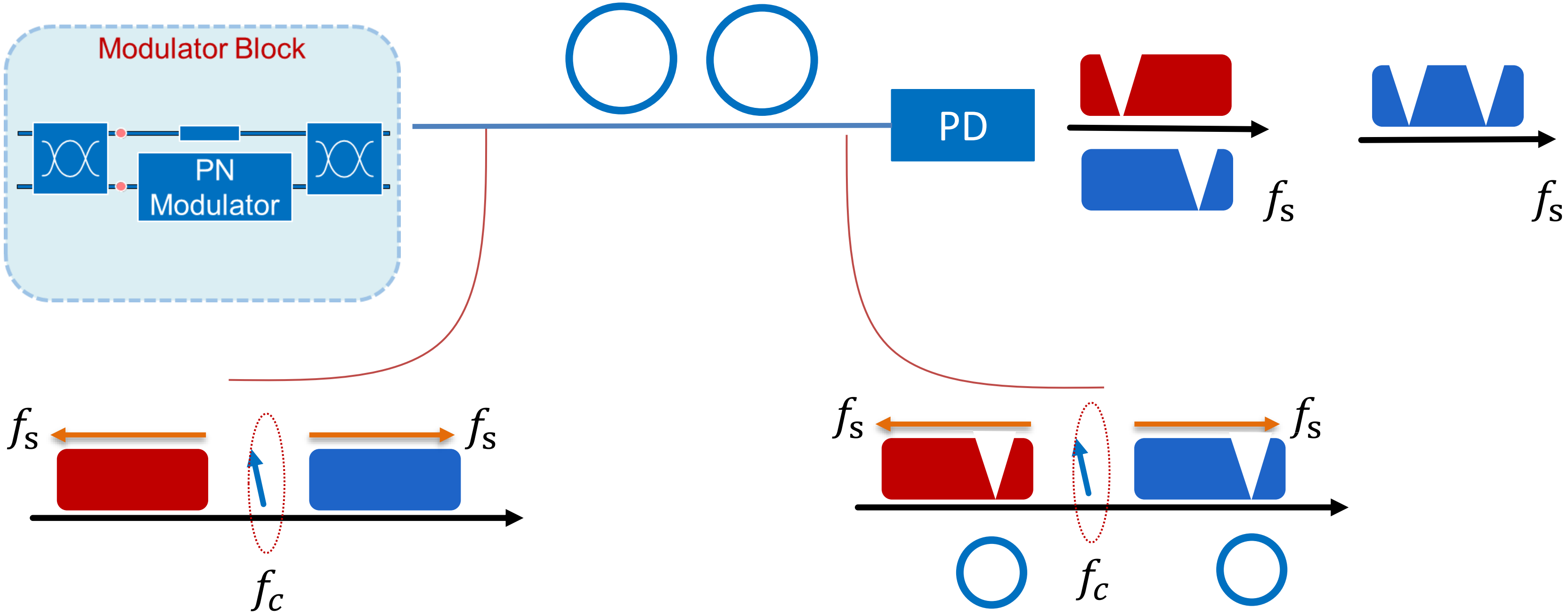




GHENT UNIVERSITY
imec

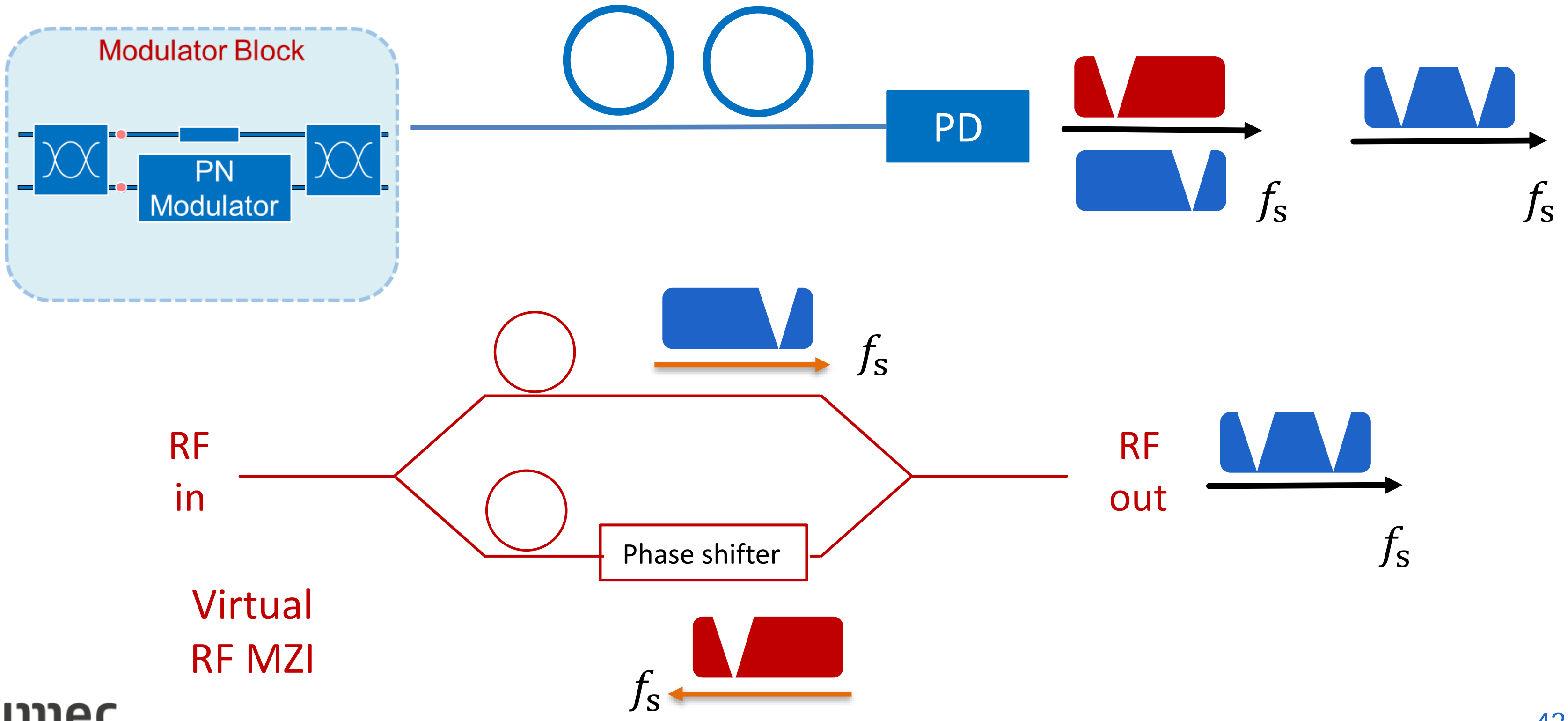
SINGLE-CHIP PROCESSOR: MICROWAVE PHOTONIC FILTER

If we add optical ring resonators in the link



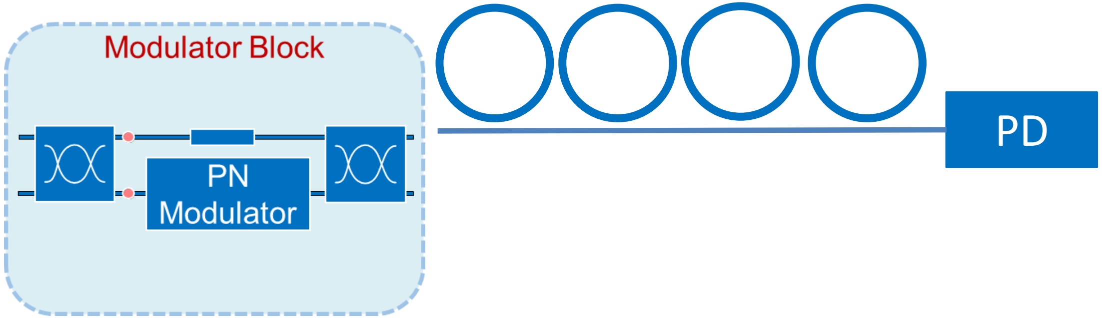
Single-Chip Processor: Microwave photonic filter

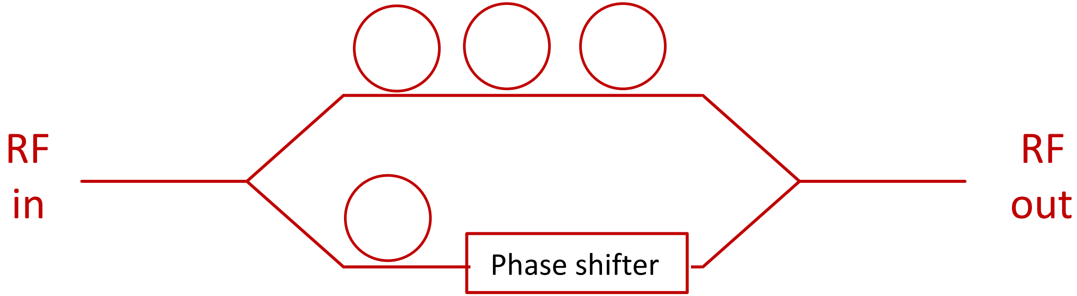
If we add optical ring resonators in the link



Single-Chip Processor: Microwave signal filter

If we add more optical ring resonators in the link





Virtual RF MZI

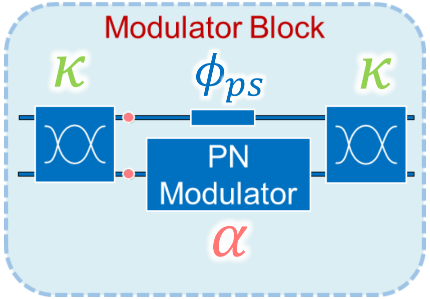
It is also a sum or diff of two all pass filters

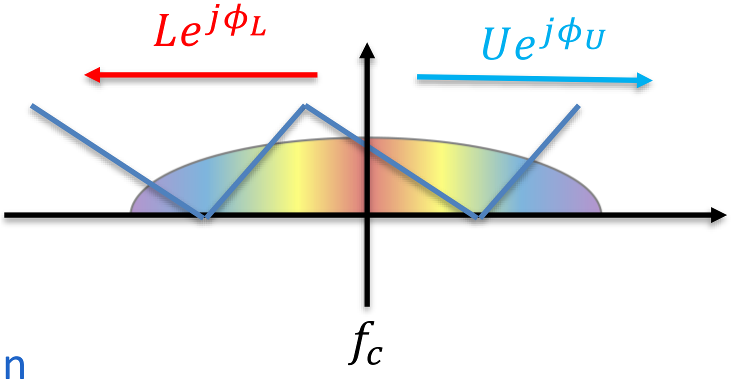
Single-Chip Processor: Microwave photonic filter

The full output signal:

$$|H_{\omega_s}| = |2A_1A_0C\sqrt{U^2 + L^2 - 2ULcos(\phi_U + \phi_L - 2(\phi_C + \phi_{A_0}))}|$$

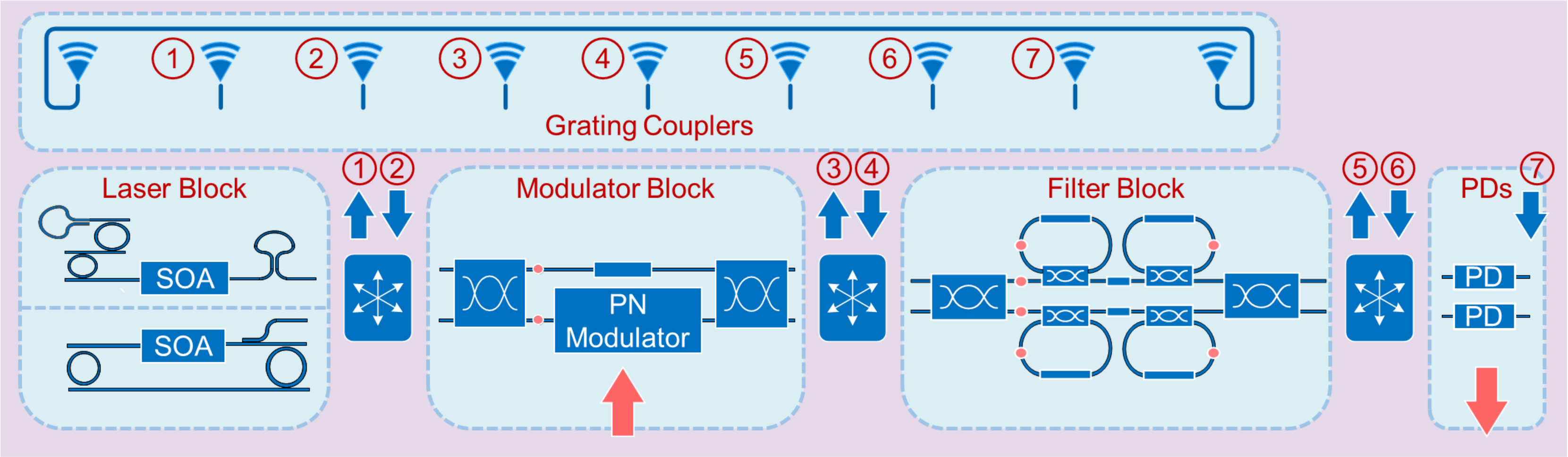
Which $A_1 = J_1(1-\kappa)\alpha$, $\boldsymbol{A_0} = (1-\kappa)\alpha J_0 - \kappa e^{j\phi_{ps}} = A_0 e^{j\phi_{A_0}}$



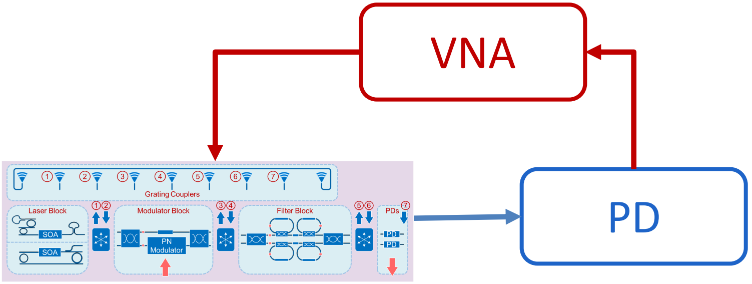


A full mapping from optical domain to RF domain

Single-Chip Processor: Microwave photonic filter

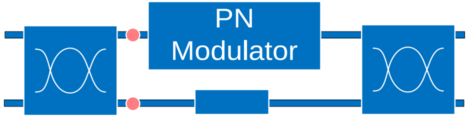


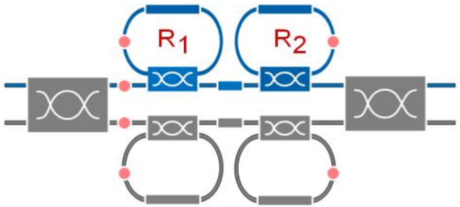
Single-Chip Processor: Microwave Photonic Filter

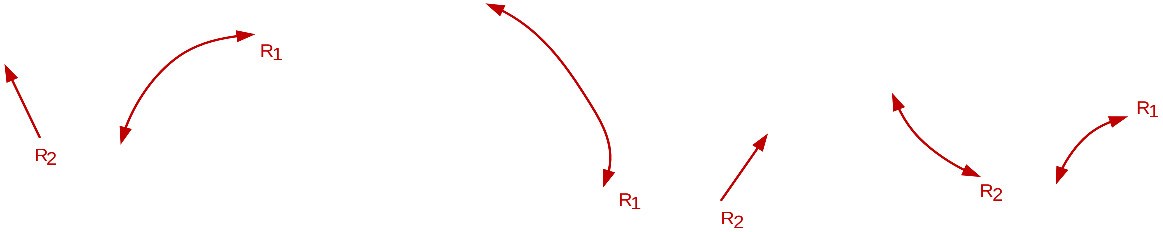


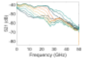
Matched the ring-loaded MZI results in optical domain

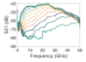
Filter Q factor limited

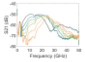




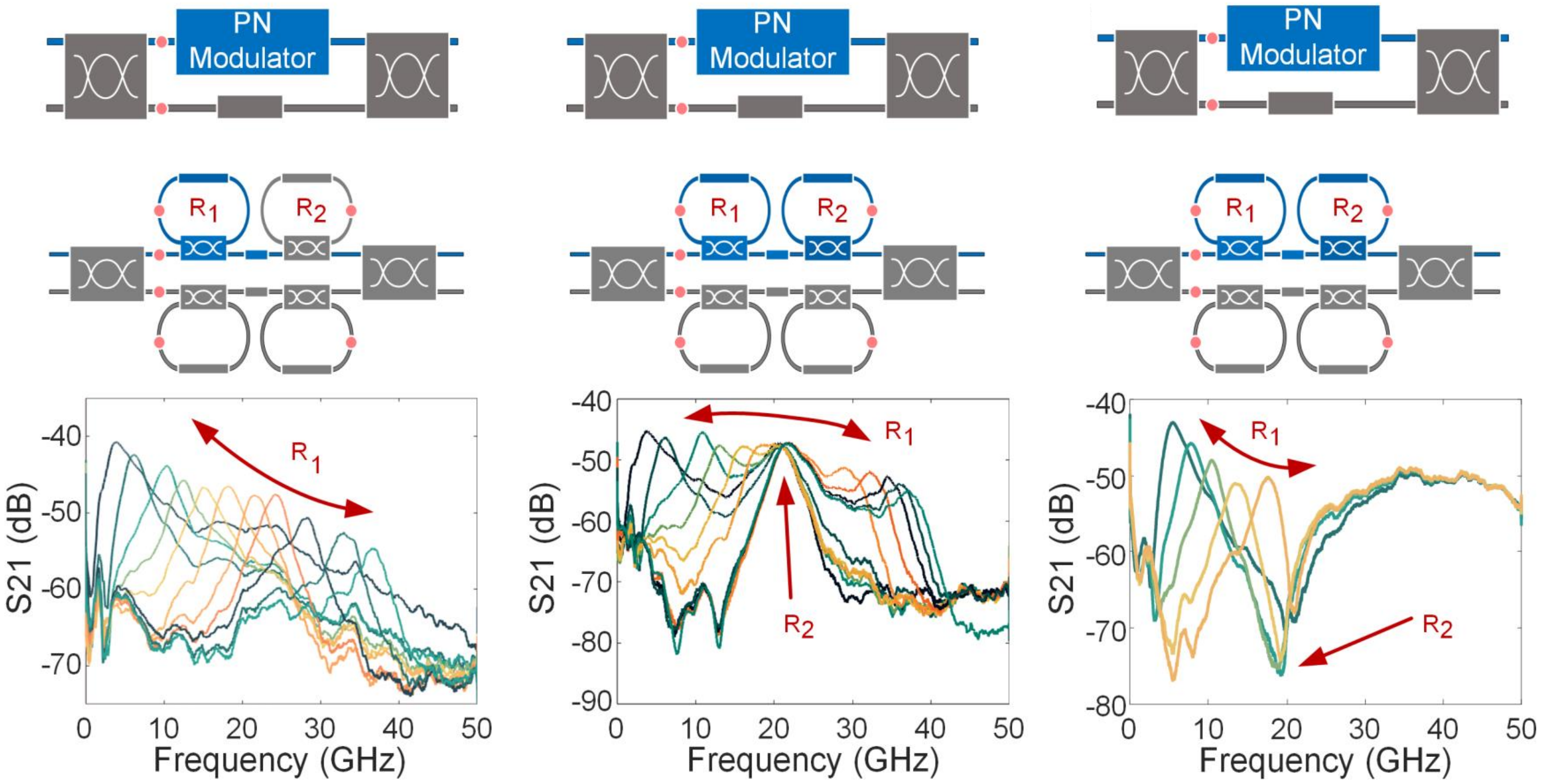






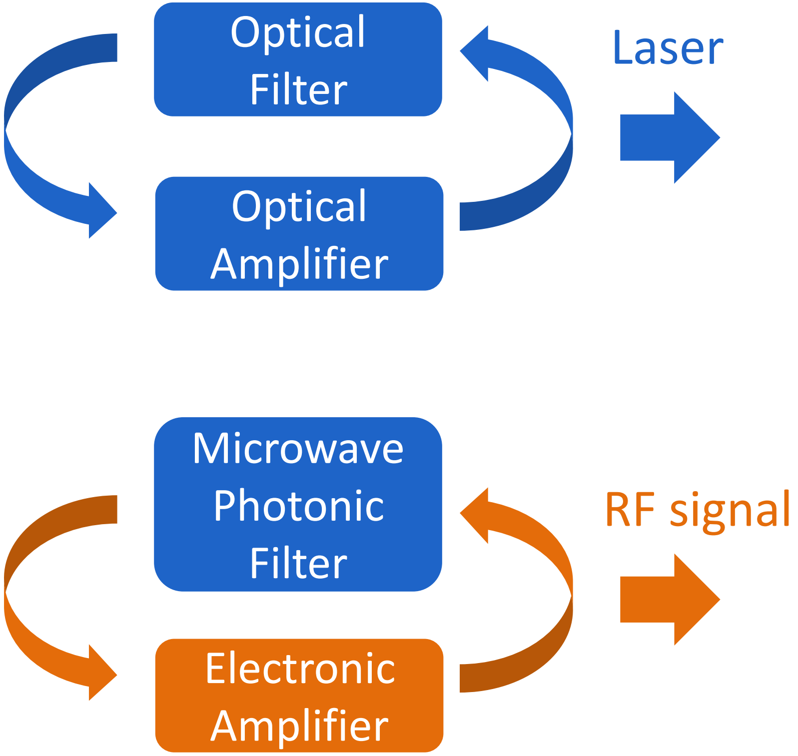


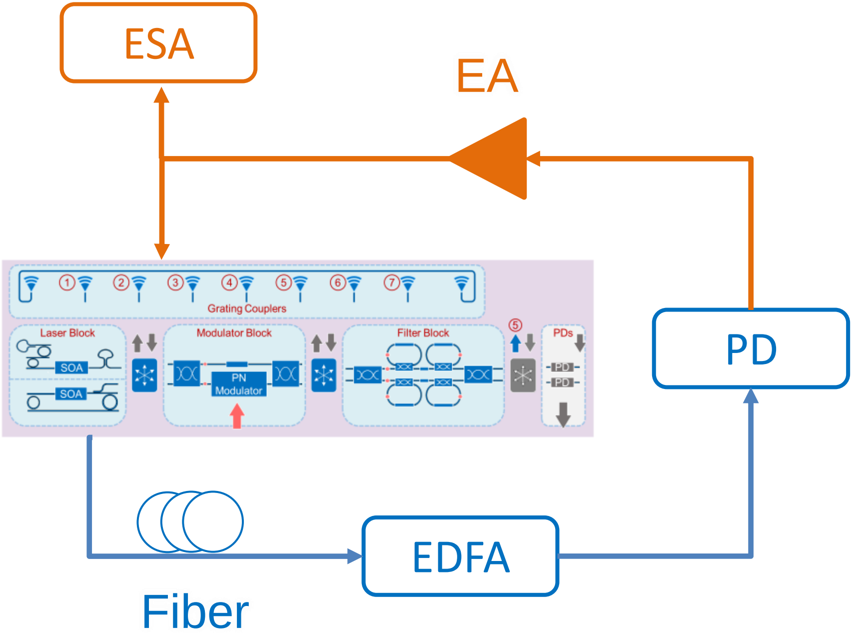
Single-Chip Processor: Microwave Photonic Filter



GHENT UNIVERSITY

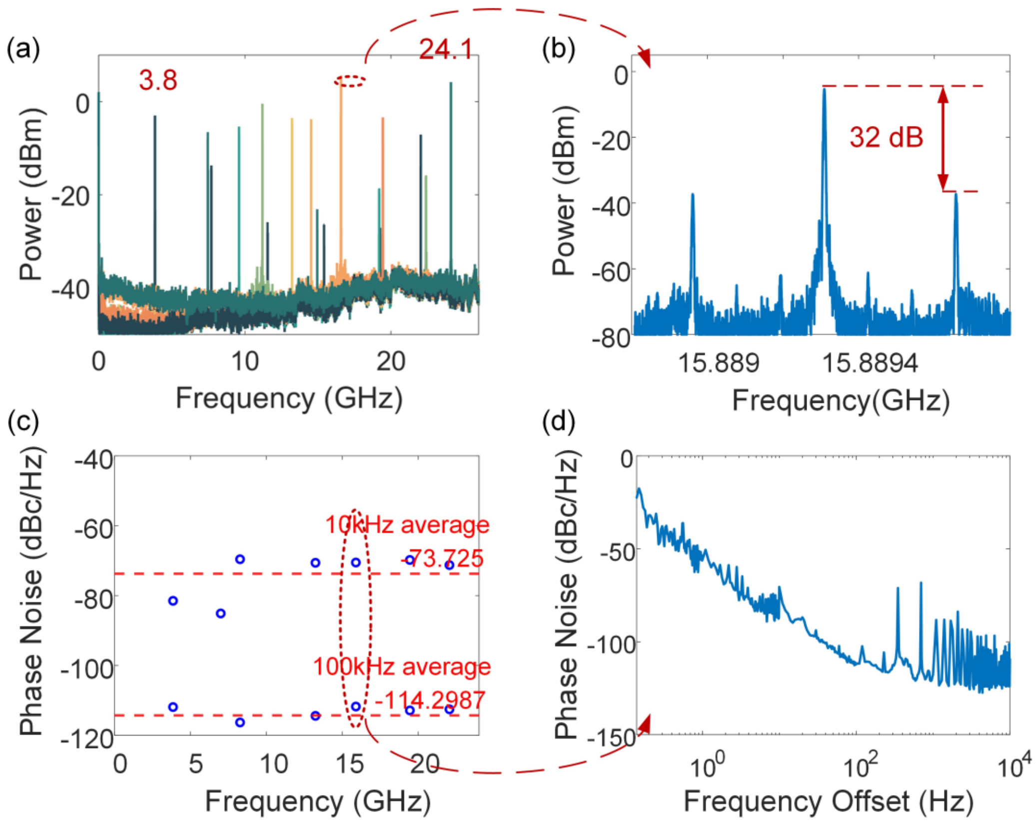
Single-Chip Processor: Opto-Electronic Oscillator





GHENT UNIVERSITY imec

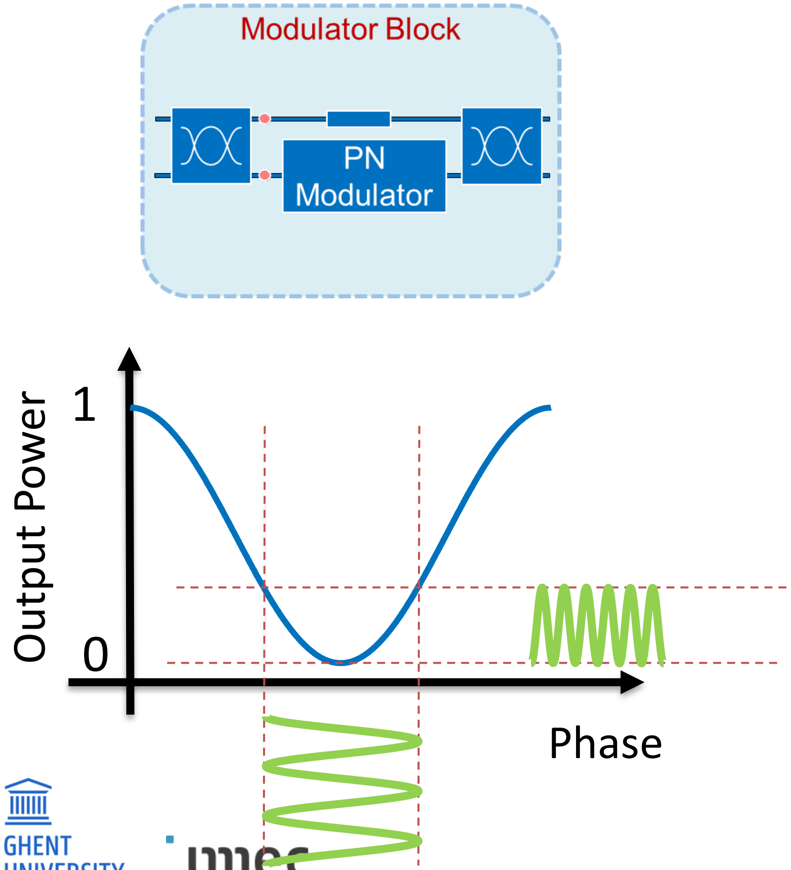
Single-Chip Processor: Opto-Electronic Oscillator

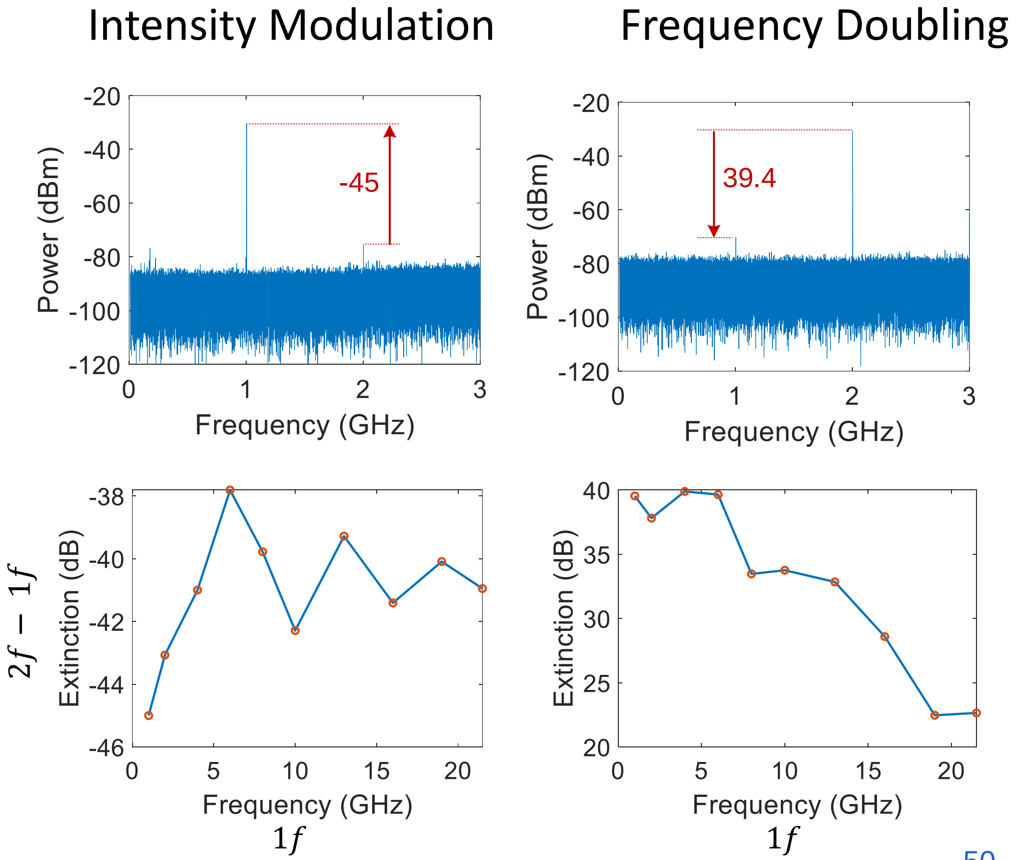


GHENT UNIVERSITY

imec

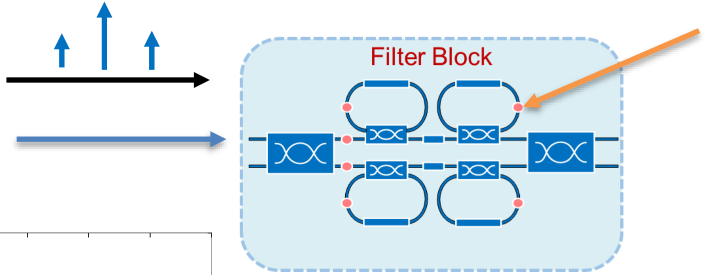
Single-Chip Processor: RF Frequency Doubling



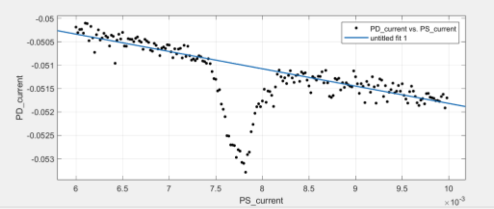


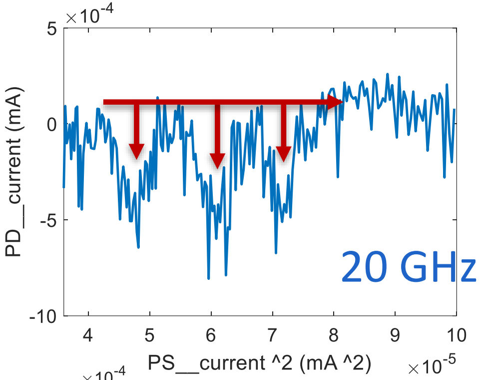
SINGLE-CHIP PROCESSOR: RF FREQUENCY MEASUREMENT / OPTICAL WAVELENGTH METER

Spectrum (RF) Measurement

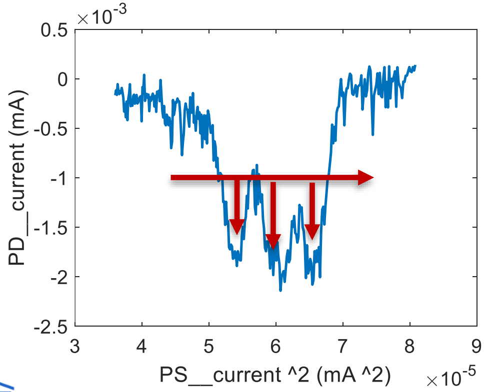


Ring phase turned
Check PD in ring

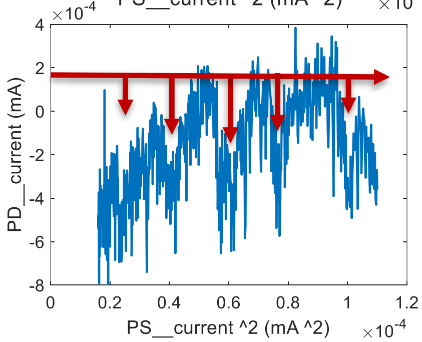




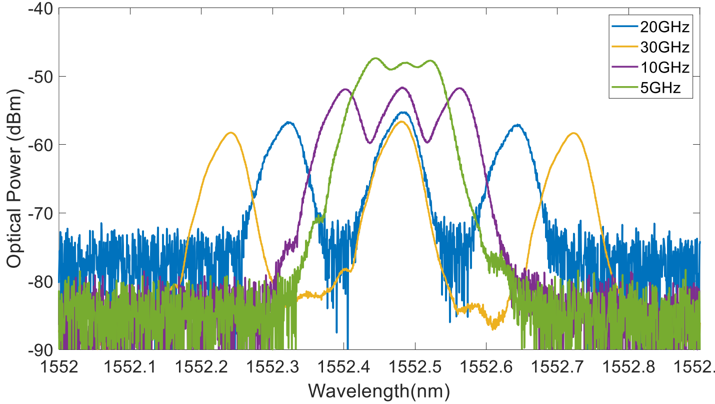
20 GHz



10 GHz



30 GHz



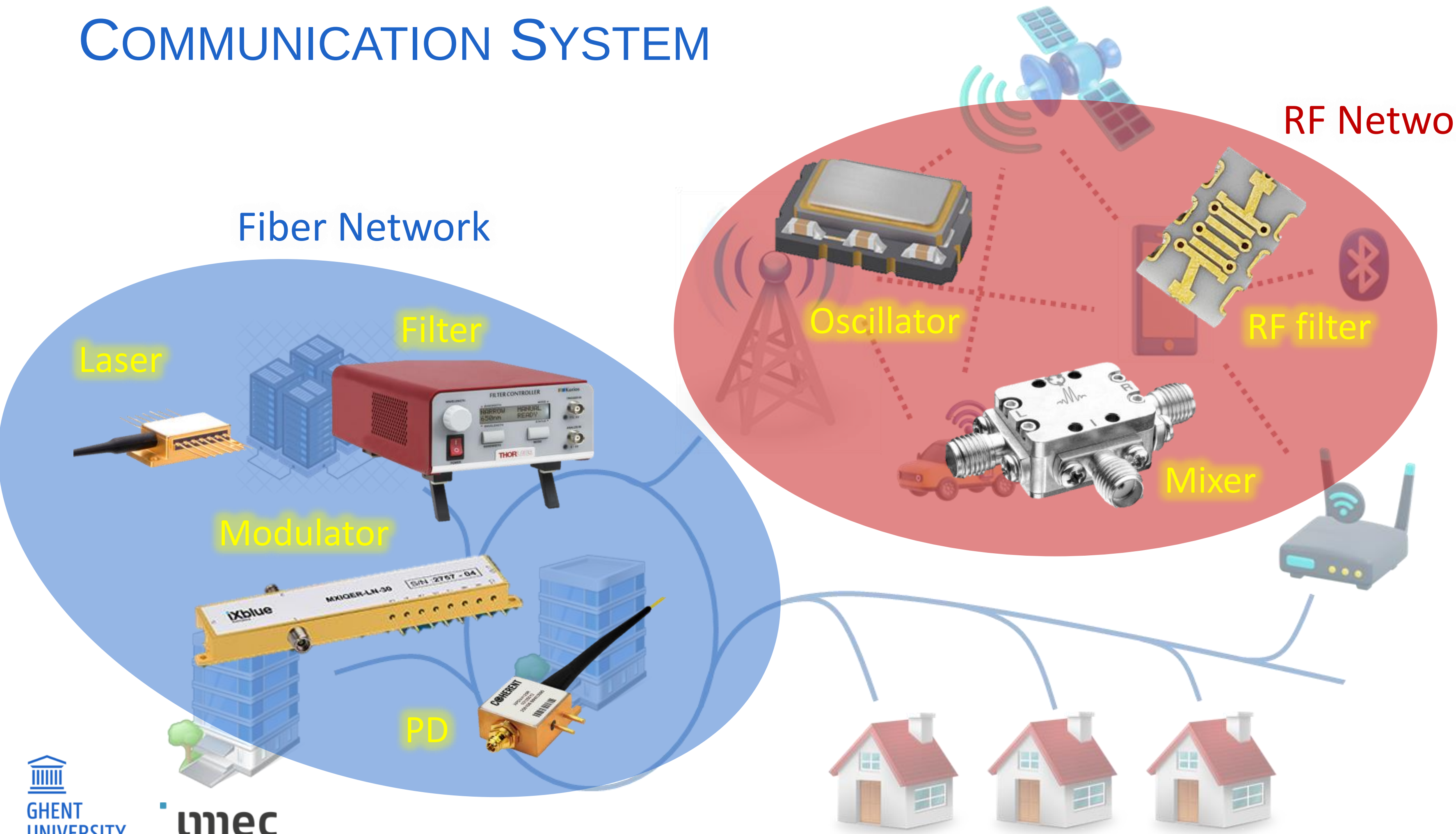
5GHz cannot distinguish

Conclusion

- A fully on-chip signal processor

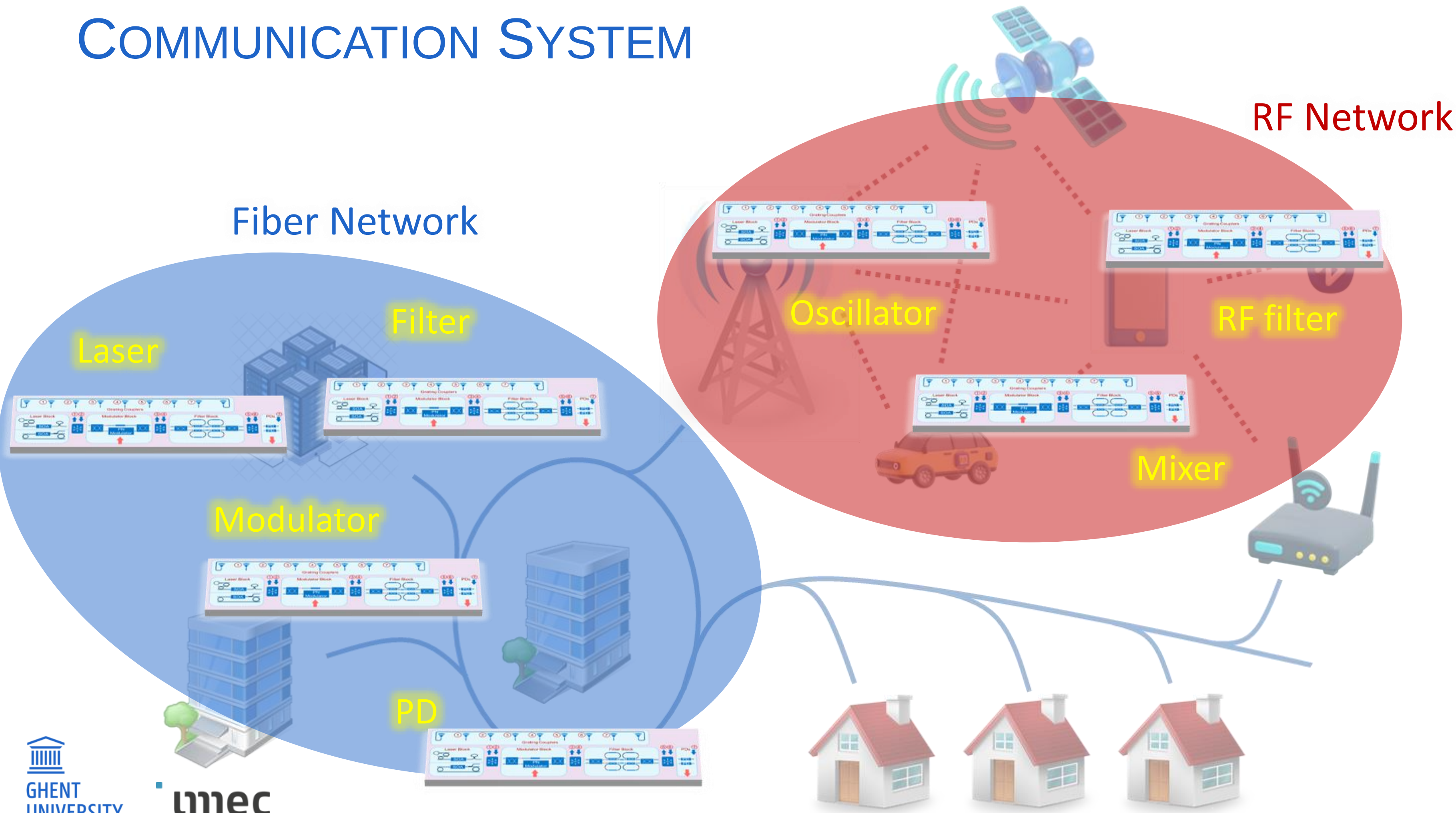
$E = A\cos(\omega t + \phi)$	**Optical Network**	**RF Network**
Signal Generation	Lasing on-chip	Tunable OEO Frequency Doubling
Signal loading	Reconfigurable Modulation	Frequency Doubling RF mixing
Signal Filtering (Complex)	Reconfigurable 4 Ring-loaded MZI	Reconfigurable RF photonic filters
Signal Detection	Wavelength meter Monitors and RF PD	Frequency measurement RF mixing

Communication System



GHENT UNIVERSITY
imec

Communication System



GHENT UNIVERSITY imec

Future Work

RF gain is too low

- Transimpedance amplifier (TIA) is needed
  → Enhance on-chip PDs
- SOA booster
  → Get higher laser power
- Better modulator design
  → Enhance modulation efficiency


Thank you

PHOTONICS RESEARCH GROUP

Hong Deng

PhD Candidate

E Hong.deng@ugent.be

T

@PhotonicsUGent

www.photonics.intec.ugent.be

GHENT UNIVERSITY

imec embracing a better life

FACULTY OF ENGINEERING AND ARCHITECTURE

nb-photonics Center for Nano- and Biophotonics Ghent University